7 0 1 6 8 1 0 3 2

DOE/RW-0070
Volume 2 of 3

HQZ. 19870302.0325

Nuclear Waste Policy Act
(Section 112)

Environmental Assessment

Reference Repository Location, Hanford Site, Washington

Volume II

May 1986

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

TABLE OF CONTENTS

Page

FOREWORD iii

ABSTRACT v

EXECUTIVE SUMMARY 1

1 PROCESS FOR SELECTING FOR SITES GEOLOGIC REPOSITORIES 1-1
1.1 Introduction 1-1
1.1.1 The geologic repository concept 1-1
1.1.2 The nuclear waste policy act of 1982 1-2
1.1.3 The environmental assessment 1-3
1.2 Summary of the overall decision process 1-5
1.2.1 Site screening 1-5
1.2.2 Salt sites 1-7
1.2.2.1 Salt domes in the Gulf Coast Salt dome basin of Mississippi and Louisiana 1-8
1.2.2.2 Bedded salt in Davis Canyon and Lavender Canyon, Utah 1-9
1.2.2.3 Bedded salt in Deaf Smith and Swisher Counties, Texas 1-10
1.2.3 Sites in Basalt and Tuff 1-11
1.2.3.1 Basalt lava in the Pasco Basin, Washington . . 1-11
1.2.3.2 Tuff in the Southern Great Basin, Nevada . . . 1-12
1.2.4 Nomination of sites for characterization 1-14
1.2.5 Final steps in the site-selection process 1-15
1.3 Evaluation of potentially acceptable sites against the disqualifying conditions of the guidelines and grouping into geohydrologic settings 1-16
1.3.1 Evaluation against the disqualifying conditions 1-16
1.3.2 Diversity of geohydrologic settings and types of host rock 1-16
1.3.2.1 Geohydrologic classification system 1-17
1.3.2.2 Distinct differences among the geohydrologic settings and host rocks 1-19

References for Chapter 1 1-22

SUMMARY 2-i

2 DECISION PROCESS BY WHICH THE SITE PROPOSED FOR NOMINATION WAS IDENTIFIED 2-1
2.1 Geohydrologic setting 2-1
2.1.1 Regional geology 2-1
2.1.1.1 Stratigraphy 2-5
2.1.1.2 Structure 2-9

TABLE OF CONTENTS (Continued)

			Page
		2.1.1.2.1 Yakima Fold Belt subprovince	2-11
		2.1.1.2.2 Palouse subprovince and paleoslope	2-15
		2.1.1.2.3 Blue Mountains subprovince	2-17
	2.1.1.3 Seismicity		2-18
2.1.2 Tectonics			2-25
2.1.3 Regional surface hydrology			2-26
2.1.4 Regional ground-water hydrology			2-30
	2.1.4.1 Regional ground-water chemistry		2-36
	2.1.4.2 Ground-water use in the Columbia Plateau and Pasco Basin		2-40
	2.1.4.3 Regional ground-water management		2-45
2.2 Site-screening process and identification of a candidate horizon at the Hanford Site			2-46
2.2.1 Identification of a reference repository location			2-47
	2.2.1.1 Identification of site localities		2-49
	2.2.1.2 Identification and ranking of candidate sites		2-52
2.2.2 Identification of principal borehole and exploratory shaft sites			2-59
2.2.3 Identification of a preferred candidate horizon			2-64
	2.2.3.1 Application of decision analysis to the proposed candidate horizons		2-68
	2.2.3.2 Application of expert judgment to the proposed candidate horizons		2-71
2.3 Summary of the evaluation of the potentially acceptable site within the geohydrologic setting			2-72
2.3.1 Geohydrology			2-72
	2.3.1.1 Disqualifying condition		2-72
	2.3.1.2 Summary of the geohydrology disqualifier analysis		2-72
2.3.2 Erosion			2-75
	2.3.2.1 Disqualifying condition		2-75
	2.3.2.2 Summary of the erosion disqualifier analysis		2-75
2.3.3 Dissolution			2-75
	2.3.3.1 Disqualifying condition		2-75
	2.3.3.2 Summary of the dissolution disqualifier analysis		2-75
2.3.4 Tectonics			2-75
	2.3.4.1 Disqualifying condition		2-75
	2.3.4.2 Summary of the tectonics disqualifier analysis		2-76
2.3.5 Natural resources			2-76
	2.3.5.1 Disqualifying conditions		2-76
	2.3.5.2 Summary of the natural resources disqualifier analysis		2-76

TABLE OF CONTENTS (Continued)

	Page
2.3.6 Population density and distribution	2-77
2.3.6.1 Disqualifying conditions	2-77
2.3.6.2 Summary of the population density and distribution disqualifier analysis	2-77
2.3.7 Offsite installations and operations	2-77
2.3.7.1 Disqualifying condition	2-77
2.3.7.2 Summary of the offsite installations and operations disqualifier analysis	2-78
2.3.8 Environmental quality	2-78
2.3.8.1 Disqualifying conditions	2-78
2.3.8.2 Summary of the environmental quality disqualifier analysis	2-79
2.3.9 Socioeconomic impacts	2-79
2.3.9.1 Disqualifying condition	2-79
2.3.9.2 Summary of the socioeconomic impacts disqualifier analysis	2-79
2.3.10 Rock characteristics	2-80
2.3.10.1 Disqualifying condition	2-80
2.3.10.2 Summary of the rock characteristics disqualifier analysis	2-80
2.3.11 Hydrology	2-80
2.3.11.1 Disqualifying condition	2-80
2.3.11.2 Summary of the hydrology disqualifier analysis	2-80
2.3.12 Tectonics	2-81
2.3.12.1 Disqualifying condition	2-81
2.3.12.2 Summary of the tectonics disqualifier analysis	2-81
References for Chapter 2	2-82
SUMMARY	3-i
3 THE SITE	3-1
3.1 Location and topography	3-1
3.2 Geologic conditions	3-1
3.2.1 Physiography and geomorphology	3-1
3.2.2 Stratigraphy	3-8
3.2.2.1 Pre-Columbia River basalt rocks	3-10
3.2.2.2 Grande Ronde Basalt	3-12
3.2.2.3 Cohassett flow	3-15
3.2.2.4 Wanapum Basalt	3-28
3.2.2.4.1 Frenchman Springs Member	3-28
3.2.2.4.2 Roza Member	3-29
3.2.2.4.3 Priest Rapids Member	3-32
3.2.2.5 Saddle Mountains Basalt	3-33
3.2.2.5.1 Umatilla Member	3-33
3.2.2.5.2 Esquatzel Member	3-34
3.2.2.5.3 Pomona Member	3-35
3.2.2.5.4 Elephant Mountain Member	3-36

TABLE OF CONTENTS (Continued)

Page

3.2.2.6 Ellensburg Formation 3-37
3.2.2.7 Ringold Formation 3-37
3.2.2.8 Plio-Pleistocene unit 3-41
3.2.2.9 Hanford Formation 3-41
3.2.3 Structure and tectonics 3-43
3.2.3.1 Wahluke syncline 3-55
3.2.3.2 Umtanum Ridge-Gable Mountain structure 3-55
3.2.3.3 Cold Creek syncline 3-57
3.2.3.3.1 Top-of-basalt structures using borehole data 3-58
3.2.3.3.2 Northwest-trending strike-slip faults 3-59
3.2.3.3.3 Small-scale strain features 3-59
3.2.3.3.4 Geophysical features in and around the reference repository location 3-60
3.2.3.4 Yakima Ridge anticline 3-62
3.2.3.5 Benson Ranch syncline 3-63
3.2.3.6 Pasco syncline 3-63
3.2.3.7 Rattlesnake-Wallula alignment 3-63
3.2.3.8 Structural analysis 3-64
3.2.4 Seismicity of the reference repository location and vicinity 3-67
3.3 Hydrologic conditions 3-71
3.3.1 Surface water 3-71
3.3.1.1 Pasco Basin 3-71
3.3.1.2 Hanford Site 3-73
3.3.1.3 Surface flooding potential 3-75
3.3.1.3.1 Flood history of the Columbia River 3-76
3.3.1.3.2 Flood history of the Yakima River 3-76
3.3.1.3.3 Flood potential 3-78
3.3.1.3.4 Cold Creek watershed 3-82
3.3.1.3.5 Flash flood potential within the reference repository location . . . 3-83
3.3.1.3.6 Proposed dam site 3-83
3.3.1.4 Surface-water use within the Pasco Basin 3-87
3.3.1.5 Surface-water demand 3-88
3.3.1.6 Surface-water intakes within the Pasco Basin 3-88
3.3.2 Ground water 3-88
3.3.2.1 Potential ground-water pathways 3-114
3.3.2.1.1 Flow interiors 3-114
3.3.2.1.2 Flow contacts and sedimentary interbeds 3-119
3.3.2.1.3 Bedrock structures 3-120
3.3.2.2 Alternative ground-water flow concepts 3-122

TABLE OF CONTENTS (Continued)

Page

3.4 Environmental setting 3-125
3.4.1 Land use 3-125
3.4.1.1 Agricultural use 3-126
3.4.1.2 Federal government activities 3-126
3.4.1.2.1 100 Areas 3-130
3.4.1.2.2 200 Areas 3-131
3.4.1.2.3 300 Area 3-134
3.4.1.2.4 400 Area 3-135
3.4.1.2.5 600 Area 3-135
3.4.1.3 Other land uses 3-136
3.4.2 Terrestrial and aquatic ecosystems 3-138
3.4.2.1 Vegetation 3-139
3.4.2.2 Mammals 3-142
3.4.2.3 Birds 3-142
3.4.2.4 Reptiles and amphibians 3-145
3.4.2.5 Threatened and endangered species 3-145
3.4.2.6 Columbia River habitat 3-146
3.4.2.6.1 Nonfisheries resources 3-147
3.4.2.6.2 Fisheries resources 3-147
3.4.2.6.3 Water quality 3-148
3.4.2.7 Radiological conditions 3-152
3.4.2.7.1 Environmental surveillance reports 3-152
3.4.2.7.2 Environmental status reports 3-152
3.4.2.7.3 Ground-water surveillance reports 3-152
3.4.2.7.4 Radiation sources 3-153
3.4.2.7.5 Radiation exposures 3-153
3.4.3 Meteorological conditions and air quality 3-155
3.4.3.1 Wind 3-155
3.4.3.2 Temperature and humidity 3-159
3.4.3.3 Precipitation 3-159
3.4.3.4 Dispersion conditions 3-159
3.4.3.5 Air quality 3-160
3.4.4 Noise 3-163
3.4.5 Aesthetic resources 3-163
3.4.6 Archaeological, cultural, and historical resources 3-164
3.5 Transportation 3-165
3.5.1 Railroad service 3-165
3.5.1.1 Burlington Northern Railroad 3-167
3.5.1.2 Union Pacific Railroad 3-167
3.5.1.3 U.S. Department of Energy railroad 3-167
3.5.2 Highway service 3-168
3.5.2.1 Highway traffic and accident data 3-168
3.5.2.2 Highway transportation disruptions due to weather conditions 3-171
3.5.3 Repository access routes 3-174

TABLE OF CONTENTS (Continued)

	Page
3.6 Socioeconomic conditions	3-175
3.6.1 Population density and distribution	3-177
3.6.2 Economic conditions	3-183
3.6.3 Community services	3-188
3.6.3.1 Housing	3-190
3.6.3.2 Public water supply	3-190
3.6.3.3 Waste-water treatment	3-194
3.6.3.4 Solid waste disposal	3-194
3.6.3.5 Public safety	3-196
3.6.3.6 Health-care and social services	3-198
3.6.3.7 Public schools	3-198
3.6.3.8 Local transportation	3-198
3.6.4 Social conditions	3-200
3.6.5 Fiscal conditions and government structure	3-202
3.6.6 Affected Indians	3-207
3.6.6.1 Reservation setting for the Confederated Tribes and Bands of the Yakima Nations	3-211
3.6.6.2 Reservation setting for the Confederated Tribes of the Umatilla Indian Reservation	3-213
3.6.6.3 Reservation setting for the Nez Perce Indian Tribe	3-214
References	3-216
SUMMARY	4-i
4 EXPECTED EFFECTS OF SITE-CHARACTERIZATION ACTIVITIES	4-1
4.1 Site-characterization activities	4-2
4.1.1 Field studies	4-2
4.1.1.1 Lithologic characterization	4-4
4.1.1.1.1 Stratigraphic setting	4-4
4.1.1.1.2 Intraflow structures	4-4
4.1.1.1.3 Primary fracture characterization	4-4
4.1.1.1.4 Mineralogy and petrology	4-5
4.1.1.2 Tectonic characterization	4-5
4.1.1.2.1 Structural setting	4-5
4.1.1.2.2 Contemporary deformation	4-5
4.1.1.2.3 Tectonic modeling	4-6
4.1.1.3 Hydrologic parameter testing	4-6
4.1.1.3.1 Large-scale hydrologic stress tests	4-6
4.1.1.3.2 Small-scale hydrologic tests	4-6
4.1.1.3.3 Tracer tests	4-7
4.1.1.3.4 Mud effects	4-7
4.1.1.4 Ground-water monitoring	4-7
4.1.1.4.1 New piezometers	4-7
4.1.1.4.2 Existing piezometers	4-7

TABLE OF CONTENTS (Continued)

	Page
4.1.1.4.3 Drill and test hydraulic heads	4-8
4.1.1.4.4 Bridge plug installations	4-8
4.1.1.5 Hydrochemical characterization	4-8
4.1.1.5.1 Ground-water sampling	4-8
4.1.1.5.2 Sampling techniques	4-8
4.1.1.5.3 Radionuclide transport	4-9
4.1.1.5.4 Geochemical modeling	4-9
4.1.1.6 Exploratory shafts	4-9
4.1.1.6.1 Construction	4-10
4.1.1.6.2 Geologic characterization	4-13
4.1.1.6.3 Hydrologic characterization	4-13
4.1.1.6.4 Geomechanics characterization	4-14
4.1.1.6.5 Final disposition	4-15
4.1.1.7 Surface-water hydrology	4-16
4.1.2 Other activities	4-16
4.1.2.1 Laboratory tests	4-16
4.1.2.2 Socioeconomic activities	4-16
4.1.2.3 Environmental studies	4-17
4.1.2.4 Geochemistry studies	4-18
4.1.2.4.1 Reduction-oxidation conditions and other ground-water characteristics in the waste package and adjacent rock	4-18
4.1.2.4.2 Radionuclide reactivity and transport in the waste package and adjacent host rock	4-18
4.2 Expected effects of site characterization	4-19
4.2.1 Expected effects on the physical environment	4-19
4.2.1.1 Geology	4-19
4.2.1.2 Hydrology	4-19
4.2.1.2.1 Surface water	4-20
4.2.1.2.2 Ground water	4-22
4.2.1.3 Effects on the environment	4-23
4.2.1.3.1 Ecosystems	4-23
4.2.1.3.2 Air quality	4-27
4.2.1.3.3 Noise	4-33
4.2.1.3.4 Aesthetic	4-35
4.2.1.3.5 Archaeological, cultural, and historical resources	4-35
4.2.1.3.6 Radiological	4-35
4.2.2 Socioeconomics	4-36
4.2.2.1 Population distribution	4-36
4.2.2.2 Economic conditions	4-38
4.2.2.3 Community services	4-38
4.2.2.4 Social conditions	4-40
4.2.2.5 Fiscal conditions and government structure	4-40
4.2.2.6 Land use, access, and surface and mineral rights	4-40

TABLE OF CONTENTS (Continued)

Page

4.2.3 Transportation effects 4-41
4.2.4 Occupational safety and health risks 4-42
4.3 Alternative site-characterization activities that would avoid adverse impacts 4-43
References for Chapter 4 4-45

SUMMARY 5-i

5 REGIONAL AND LOCAL EFFECTS OF LOCATING A REPOSITORY AT THE REFERENCE REPOSITORY LOCATION 5-1
5.1 The repository 5-1
5.1.1 Requirements for the 1982 conceptual design 5-9
5.1.1.1 Repository life cycle 5-10
5.1.1.2 Projected work force and major material commitments 5-11
5.1.2 Description of 1982 conceptual design 5-11
5.1.2.1 Surface facilities 5-12
5.1.2.1.1 Ventilation 5-19
5.1.2.1.2 Radiation-monitoring systems 5-20
5.1.2.1.3 Radioactive waste control and disposal 5-20
5.1.2.1.4 Nonradioactive waste control and disposal 5-21
5.1.2.2 Subsurface facilities 5-22
5.1.3 Design studies 5-23
5.1.3.1 Optimization and alternative studies 5-23
5.1.3.2 Repository underground layout study 5-26
5.1.3.2.1 Design functions 5-26
5.1.3.2.2 Design features 5-26
5.1.3.2.3 Design approach and assumptions 5-30
5.1.3.2.4 Repository underground layout study results 5-31
5.1.3.3 Two-phase waste-receipt repository study 5-34
5.1.4 Decommissioning and closure 5-35
5.1.5 Waste package description 5-35
5.1.5.1 Waste form 5-35
5.1.5.2 Container 5-40
5.1.5.3 Waste container configuration and packing 5-40
5.1.6 Programmatic issues affecting design 5-40
5.1.6.1 Monitored retrievable storage 5-41
5.1.6.2 Minimum waste age 5-42
5.1.6.3 Retrievability 5-43
5.1.7 Transportation assessment summary 5-43

TABLE OF CONTENTS (Continued)

	Page
5.2 Expected regional and local effects	5-45
5.2.1 Expected effects on the physical environment	5-45
5.2.1.1 Geology	5-47
5.2.1.2 Hydrology	5-47
5.2.1.2.1 Surface water	5-47
5.2.1.2.2 Ground water	5-48
5.2.1.3 Environmental setting	5-48
5.2.1.3.1 Ecosystems	5-48
5.2.1.3.2 Air quality	5-53
5.2.1.3.3 Noise	5-56
5.2.1.3.4 Aesthetic	5-58
5.2.1.3.5 Archaeological, cultural, and historical resources	5-58
5.2.1.3.6 Radiological	5-58
5.2.2 Expected effects of transportation	5-59
5.2.2.1 Radioactive waste shipment bases	5-60
5.2.2.1.1 Authorized system	5-61
5.2.2.1.2 Improved performance system	5-65
5.2.2.2 Types of nonradioactive shipments	5-66
5.2.2.3 Regional impacts of nuclear waste transport	5-67
5.2.2.3.1 Highway transport	5-68
5.2.2.3.2 Railroad transport	5-73
5.2.2.4 Potential barge transport of western spent fuel	5-73
5.2.2.5 Hanford Site defense high-level waste transportation impacts	5-78
5.2.3 Expected effects on socioeconomic conditions	5-78
5.2.3.1 Population density and distribution	5-83
5.2.3.2 Economic conditions	5-84
5.2.3.3 Community services	5-87
5.2.3.4 Social conditions	5-89
5.2.3.5 Fiscal conditions and government structures	5-90
5.2.3.6 Land use, access, and surface and mineral rights	5-92
5.3 Occupational safety and health risks	5-93
References for Chapter 5	5-95
SUMMARY	6-i
6 SUITABILITY OF THE HANFORD SITE FOR SITE CHARACTERIZATION AND FOR DEVELOPMENT AS A REPOSITORY	6-1
6.1 The U.S. Department of Energy siting guidelines	6-1
6.1.1 Format and structure of the guidelines	6-1
6.1.2 Use of the siting guidelines in evaluating site suitability	6-3
6.1.3 Division of the guidelines into categories	6-4
6.1.4 Format for the presentation of site evaluations	6-5

TABLE OF CONTENTS (Continued)

	Page
6.2 Suitability of the site for development as a repository; evaluation against the guidelines that do not require site characterization	6-7
6.2.1 Technical guidelines	6-7
6.2.1.1 Human interference	6-7
6.2.1.1.1 Qualifying condition	6-7
6.2.1.1.2 Evaluation process	6-7
6.2.1.1.3 Favorable condition	6-9
6.2.1.1.4 Potentially adverse condition	6-9
6.2.1.1.5 Conclusion on qualifying condition	6-10
6.2.1.2 Population density and distribution	6-10
6.2.1.2.1 Qualifying condition	6-11
6.2.1.2.2 Evaluation process	6-11
6.2.1.2.3 Favorable conditions	6-13
6.2.1.2.4 Potentially adverse conditions	6-13
6.2.1.2.5 Disqualifying conditions	6-15
6.2.1.2.6 Conclusions on qualifying condition	6-17
6.2.1.3 Site ownership and control	6-17
6.2.1.3.1 Qualifying condition	6-17
6.2.1.3.2 Evaluation process	6-18
6.2.1.3.3 Favorable condition	6-19
6.2.1.3.4 Potentially adverse condition	6-20
6.2.1.3.5 Conclusion on qualifying condition	6-20
6.2.1.4 Meteorology	6-21
6.2.1.4.1 Qualifying condition	6-21
6.2.1.4.2 Evaluation process	6-21
6.2.1.4.3 Favorable condition	6-22
6.2.1.4.4 Potentially adverse condition	6-23
6.2.1.4.5 Potentially adverse condition	6-23
6.2.1.4.6 Conclusion on qualifying condition	6-24
6.2.1.5 Offsite installations and operations	6-25
6.2.1.5.1 Qualifying condition	6-25
6.2.1.5.2 Evaluation process	6-25
6.2.1.5.3 Favorable condition	6-29
6.2.1.5.4 Potentially adverse condition	6-29
6.2.1.5.5 Potentially adverse condition	6-30
6.2.1.5.6 Disqualifying condition	6-30
6.2.1.5.7 Conclusions on qualifying condition	6-31
6.2.1.6 Environmental quality	6-31
6.2.1.6.1 Qualifying condition	6-31
6.2.1.6.2 Evaluation process	6-32
6.2.1.6.3 Favorable conditions	6-32

TABLE OF CONTENTS (Continued)

Page

6.2.1.6.4 Favorable condition 6-44
6.2.1.6.5 Potentially adverse condition . . . 6-45
6.2.1.6.6 Potentially adverse condition . . . 6-45
6.2.1.6.7 Potentially adverse condition . . . 6-46
6.2.1.6.8 Potentially adverse condition . . . 6-46
6.2.1.6.9 Potentially adverse condition . . . 6-47
6.2.1.6.10 Potentially adverse condition . . . 6-47
6.2.1.6.11 Disqualifying conditions 6-48
6.2.1.6.12 Conclusion on qualifying condition 6-52
6.2.1.7 Socioeconomic impacts 6-53
6.2.1.7.1 Qualifying condition 6-53
6.2.1.7.2 Evaluation process 6-53
6.2.1.7.3 Favorable condition 6-53
6.2.1.7.4 Favorable condition 6-54
6.2.1.7.5 Favorable condition 6-54
6.2.1.7.6 Favorable condition 6-55
6.2.1.7.7 Potentially adverse condition . . . 6-55
6.2.1.7.8 Potentially adverse condition . . . 6-55
6.2.1.7.9 Potentially adverse condition . . . 6-56
6.2.1.7.10 Potentially adverse condition . . . 6-56
6.2.1.7.11 Disqualifying condition 6-56
6.2.1.7.12 Conclusion on qualifying condition 6-57
6.2.1.8 Transportation 6-58
6.2.1.8.1 Qualifying condition 6-58
6.2.1.8.2 Evaluation process 6-58
6.2.1.8.3 Favorable condition 6-59
6.2.1.8.4 Favorable condition 6-60
6.2.1.8.5 Favorable condition 6-61
6.2.1.8.6 Favorable condition 6-62
6.2.1.8.7 Favorable condition 6-63
6.2.1.8.8 Favorable condition 6-65
6.2.1.8.9 Favorable condition 6-65
6.2.1.8.10 Favorable condition 6-66
6.2.1.8.11 Favorable condition 6-67
6.2.1.8.12 Potentially adverse conditions 6-67
6.2.1.8.13 Conclusion on qualifying condition 6-69
6.2.2 System guidelines 6-70
6.2.2.1 Preclosure radiological safety 6-70
6.2.2.1.1 Qualifying condition 6-70
6.2.2.1.2 Evaluation process 6-70
6.2.2.1.3 Conclusion on qualifying condition 6-71
6.2.2.2 Environment socioeconomics, and transportation 6-72
6.2.2.2.1 Qualifying condition 6-72

TABLE OF CONTENTS (Continued)

	Page
6.2.2.2.2 Evaluation process	6-73
6.2.2.2.3 Conclusion on qualifying condition	6-73
6.2.3 Conclusion regarding the suitability of the site for development as a repository	6-75
6.3 Suitability of the site for site characterization: Evaluation against the guidelines that do require site characterization	6-76
6.3.1 Postclosure technical guidelines	6-76
6.3.1.1 Geohydrology	6-76
6.3.1.1.1 Qualifying condition	6-76
6.3.1.1.2 Evaluation process	6-76
6.3.1.1.3 Favorable condition	6-77
6.3.1.1.4 Favorable condition	6-81
6.3.1.1.5 Favorable condition	6-83
6.3.1.1.6 Favorable condition	6-85
6.3.1.1.7 Favorable condition	6-92
6.3.1.1.8 Potentially adverse condition . . .	6-92
6.3.1.1.9 Potentially adverse condition . . .	6-93
6.3.1.1.10 Potentially adverse condition . . .	6-99
6.3.1.1.11 Disqualifying condition	6-99
6.3.1.1.12 Conclusion on qualifying condition	6-104
6.3.1.2 Geochemistry	6-106
6.3.1.2.1 Qualifying condition	6-106
6.3.1.2.2 Evaluation process	6-106
6.3.1.2.3 Favorable condition	6-109
6.3.1.2.4 Favorable condition	6-111
6.3.1.2.5 Favorable condition	6-112
6.3.1.2.6 Favorable condition	6-113
6.3.1.2.7 Favorable condition	6-114
6.3.1.2.8 Potentially adverse condition . . .	6-117
6.3.1.2.9 Potentially adverse condition . . .	6-123
6.3.1.2.10 Potentially adverse condition . . .	6-123
6.3.1.2.11 Conclusions on qualifying conditions	6-124
6.3.1.3 Rock characteristics	6-125
6.3.1.3.1 Qualifying condition	6-125
6.3.1.3.2 Evaluation process	6-125
6.3.1.3.3 Favorable condition	6-126
6.3.1.3.4 Favorable condition	6-130
6.3.1.3.5 Potentially adverse condition . . .	6-133
6.3.1.3.6 Potentially adverse condition . . .	6-135
6.3.1.3.7 Potentially adverse condition . . .	6-139
6.3.1.3.8 Conclusion on qualifying condition	6-139
6.3.1.4 Climatic changes	6-140
6.3.1.4.1 Qualifying condition	6-140
6.3.1.4.2 Evaluation process	6-141

TABLE OF CONTENTS (Continued)

			Page
	6.3.1.4.3	Favorable condition	6-145
	6.3.1.4.4	Favorable condition	6-147
	6.3.1.4.5	Potentially adverse condition . . .	6-147
	6.3.1.4.6	Potentially adverse condition . . .	6-148
	6.3.1.4.7	Conclusion on qualifying condition	6-148
6.3.1.5	Erosion		6-148
	6.3.1.5.1	Qualifying condition	6-148
	6.3.1.5.2	Evaluation process	6-149
	6.3.1.5.3	Favorable condition	6-151
	6.3.1.5.4	Favorable condition	6-152
	6.3.1.5.5	Favorable condition	6-152
	6.3.1.5.6	Potentially adverse condition . . .	6-153
	6.3.1.5.7	Potentially adverse condition . . .	6-154
	6.3.1.5.8	Disqualifying condition	6-154
	6.3.1.5.9	Conclusion on qualifying condition	6-155
6.3.1.6	Dissolution		6-155
	6.3.1.6.1	Qualifying condition	6-155
	6.3.1.6.2	Evaluation process	6-156
	6.3.1.6.3	Favorable condition	6-156
	6.3.1.6.4	Potentially adverse condition . . .	6-156
	6.3.1.6.5	Disqualifying condition	6-156
	6.3.1.6.6	Conclusion on qualifying condition	6-158
6.3.1.7	Tectonics		6-158
	6.3.1.7.1	Qualifying condition	6-158
	6.3.1.7.2	Evaluation process	6-158
	6.3.1.7.3	Favorable condition	6-159
	6.3.1.7.4	Potentially adverse condition . . .	6-163
	6.3.1.7.5	Potentially adverse condition . . .	6-165
	6.3.1.7.6	Potentially adverse condition . . .	6-166
	6.3.1.7.7	Potentially adverse condition . . .	6-168
	6.3.1.7.8	Potentially adverse condition . . .	6-169
	6.3.1.7.9	Potentially adverse condition . . .	6-170
	6.3.1.7.10	Disqualifying condition	6-171
	6.3.1.7.11	Conclusion on qualifying condition	6-171
6.3.1.8	Human interference		6-173
	6.3.1.8.1	Qualifying condition	6-173
	6.3.1.8.2	Evaluation process	6-173
	6.3.1.8.3	Favorable condition	6-174
	6.3.1.8.4	Favorable condition	6-177
	6.3.1.8.5	Potentially adverse condition . . .	6-177
	6.3.1.8.6	Potentially adverse condition . . .	6-178
	6.3.1.8.7	Potentially adverse condition . . .	6-179
	6.3.1.8.8	Potentially adverse condition . . .	6-179
	6.3.1.8.9	Potentially adverse condition . . .	6-180
	6.3.1.8.10	Disqualifying condition	6-181

TABLE OF CONTENTS (Continued)

Page

6.3.1.8.11 Disqualifying condition 6-182
6.3.1.8.12 Conclusion on qualifying condition 6-183
6.3.2 Postclosure system guidelines 6-184
6.3.2.1 Qualifying condition 6-184
6.3.2.2 Evaluation process 6-184
6.3.2.3 Conclusion on qualifying condition 6-186
6.3.3 Preclosure technical guidelines 6-187
6.3.3.1 Surface characteristics 6-187
6.3.3.1.1 Qualifying condition 6-187
6.3.3.1.2 Evaluation process 6-187
6.3.3.1.3 Favorable condition 6-188
6.3.3.1.4 Favorable condition 6-188
6.3.3.1.5 Potentially adverse conditions 6-188
6.3.3.1.6 Conclusion on qualifying condition 6-189
6.3.3.2 Rock characteristics 6-189
6.3.3.2.1 Qualifying condition 6-189
6.3.3.2.2 Evaluation process 6-189
6.3.3.2.3 Favorable conditions 6-190
6.3.3.2.4 Favorable condition 6-196
6.3.3.2.5 Potentially adverse condition . . . 6-205
6.3.3.2.6 Potentially adverse condition . . . 6-205
6.3.3.2.7 Potentially adverse condition . . . 6-225
6.3.3.2.8 Potentially adverse condition . . . 6-228
6.3.3.2.9 Potentially adverse condition . . . 6-230
6.3.3.2.10 Disqualifying condition 6-234
6.3.3.2.11 Conclusion on qualifying condition 6-241
6.3.3.3 Hydrology 6-241
6.3.3.3.1 Qualifying condition 6-241
6.3.3.3.2 Evaluation process 6-241
6.3.3.3.3 Favorable condition 6-242
6.3.3.3.4 Favorable condition 6-243
6.3.3.3.5 Favorable condition 6-243
6.3.3.3.6 Potentially adverse condition . . . 6-244
6.3.3.3.7 Disqualifying condition 6-245
6.3.3.3.8 Conclusion on qualifying condition 6-246
6.3.3.4 Tectonics 6-247
6.3.3.4.1 Qualifying condition 6-247
6.3.3.4.2 Evaluation process 6-247
6.3.3.4.3 Favorable condition 6-248
6.3.3.4.4 Potentially adverse condition . . . 6-250
6.3.3.4.5 Potentially adverse condition . . . 6-250
6.3.3.4.6 Potentially adverse condition . . . 6-251
6.3.3.4.7 Disqualifying condition 6-252
6.3.3.4.8 Conclusion on qualifying condition 6-253

TABLE OF CONTENTS (Continued)

Page

6.3.4 Preclosure system guideline 6-254
6.3.4.1 Ease and cost of construction, operation, and closure 6-254
6.3.4.1.1 Qualifying condition 6-254
6.3.4.1.2 Evaluation process 6-254
6.3.4.1.3 Conclusion on qualifying condition 6-255
6.3.5 Conclusion regarding the suitability of the site for site characterization 6-256
6.4 Analyses supporting the comparison with systems guidelines 6-256
6.4.1 Preclosure system guidelines analyses 6-257
6.4.1.1 Scope 6-257
6.4.1.2 Safety analysis methodology 6-257
6.4.1.3 Description of safety analysis methodology 6-259
6.4.1.3.1 System description 6-259
6.4.1.3.2 Characterization of normal operations hazards 6-260
6.4.1.3.3 Selection and characterization of accident scenarios 6-260
6.4.1.3.4 Risk analysis 6-260
6.4.1.3.5 Recommendation of preventive and mitigative measures 6-261
6.4.1.4 Evaluation of preclosure repository performance 6-261
6.4.1.4.1 Normal operating conditions 6-261
6.4.1.4.2 Analysis of releases under routine operations 6-262
6.4.1.4.3 Abnormal or accident conditions 6-263
6.4.1.4.4 Estimated dose consequences from hoist cage-drop incident 6-263
6.4.2 Postclosure system guideline analysis: A preliminary system performance assessment 6-265
6.4.2.1 Scope and objectives 6-267
6.4.2.2 Mined geologic repository subsystem descriptions 6-268
6.4.2.2.1 Waste package subsystem description 6-268
6.4.2.2.2 Repository seals subsystem description 6-269
6.4.2.2.3 Site subsystem description 6-270
6.4.2.3 Subsystem performance assessment methodology 6-271
6.4.2.3.1 Methods of analysis 6-273
6.4.2.3.2 Identification of radionuclides used in performance assessment 6-276

TABLE OF CONTENTS (Continued)

		Page
6.4.2.4	Waste package subsystem performance	6-279
6.4.2.4.1	Method of analysis	6-281
6.4.2.4.2	Analysis of container corrosion	6-282
6.4.2.4.3	Distribution of container failure	6-285
6.4.2.4.4	Estimation of release from a single container	6-285
6.4.2.4.5	Estimation of fractional radionuclide release from all containers at the waste package subsystem boundary	6-290
6.4.2.4.6	Conclusions	6-294
6.4.2.5	Repository seals subsystem performance	6-300
6.4.2.5.1	Methodology for repository seals subsystem analysis	6-301
6.4.2.5.2	Data set for repository seals subsystem	6-304
6.4.2.5.3	Results of repository seals subsystem analysis	6-304
6.4.2.6	Site subsystem performance	6-306
6.4.2.6.1	Pre-waste-emplacement ground-water travel time	6-307
6.4.2.6.2	Cumulative radionuclide release	6-319
6.4.2.7	Summary of performance assessment results	6-330
6.4.2.7.1	Performance of the waste package subsystem	6-330
6.4.2.7.2	Performance of the repository seals subsystem	6-332
6.4.2.7.3	Performance of the site subsystem	6-333
6.4.2.7.4	Performance of the total isolation system	6-333
6.4.2.8	Human intrusion and disruptive events	6-334
6.4.2.8.1	Development of methodology	6-334
6.4.2.8.2	Human interference	6-335
6.4.2.9	Preliminary performance assessment findings	6-339
6.4.2.9.1	Containment time	6-339
6.4.2.9.2	Radionuclide release rate	6-340
6.4.2.9.3	Ground-water travel time	6-341
6.4.2.9.4	Individual protection	6-342
6.4.2.9.5	Ground-water protection	6-343
6.4.2.9.6	Cumulative radionuclide release	6-344
References for Chapter 6		6-345

7 0 1 6 8 1 0 4 9

TABLE OF CONTENTS (Continued)

Page

7 COMPARATIVE EVALUATION OF NOMINATED SITES 7-1

7.1 Introduction 7-1
7.1.1 Purpose and requirements 7-1
7.1.2 Approach and organization 7-1
7.2 Comparison of the sites on the basis of the postclosure guidelines 7-3
7.2.1 Technical guidelines 7-4
7.2.1.1 Geohydrology (postclosure) 7-4
7.2.1.2 Geochemistry 7-16
7.2.1.3 Rock characteristics 7-24
7.2.1.4 Climatic changes 7-29
7.2.1.5 Erosion 7-33
7.2.1.6 Dissolution 7-36
7.2.1.7 Tectonics (postclosure) 7-40
7.2.1.8 Human interference 7-44
7.2.1.8.1 Natural resources 7-45
7.2.2 Postclosure system guidelines 7-51
7.3 Comparison of sites on the basis of preclosure guidelines . . . 7-52
7.3.1 Preclosure radiological safety 7-54
7.3.1.1 Technical guidelines 7-54
7.3.1.1.1 Population density and distribution . 7-55
7.3.1.1.2 Site ownership and control 7-59
7.3.1.1.3 Meteorology 7-62
7.3.1.1.4 Offsite installation and operations . 7-66
7.3.1.2 Preclosure system guidelines for radiological safety 7-70
7.3.2 Environment, socioeconomics, and transportation 7-72
7.3.2.1 Technical guidelines 7-72
7.3.2.1.1 Environmental quality 7-72
7.3.2.1.2 Socioeconomic impacts 7-79
7.3.2.1.3 Transportation 7-89
7.3.2.2 System guidelines on environment, socioeconomics, and transportation 7-100
7.3.3 Ease and cost of siting, construction, operation, and closure 7-106
7.3.3.1 Technical guidelines 7-106
7.3.3.1.1 Surface characteristics 7-106
7.3.3.1.2 Rock characteristics (preclosure) . . 7-110
7.3.3.1.3 Hydrology 7-117
7.3.3.1.4 Tectonics (preclosure) 7-121
7.3.3.2 System guidelines on the ease and cost of siting, construction, operation, and closure 7-127

TABLE OF CONTENTS (Continued)

	Page
GLOSSARY, LIST OF ACRONYMS AND ABBREVIATIONS	G-1
APPENDIX A TRANSPORTATION	A-1
APPENDIX B AVAILABILITY OF REFERENCES	B-1
APPENDIX C COMMENT-RESPONSE INDEX	C-1

LIST OF FIGURES

Figure	Title	Page
1-1	Potentially acceptable sites for the first repository	1-4
1-2	Geohydrologic regions of the contiguous United States	1-18
2-1	Location of the Hanford Site, southeastern Washington State	2-2
2-2	Divisions of the Columbia Intermontane Physiographic Province	2-3
2-3	Cross section of a typical flow in the Columbia River Basalt Group illustrating, in idealized form, jointing patterns and other structures	2-4
2-4	Stratigraphic nomenclature for the Columbia River Basalt Group of the Columbia Plateau	2-6
2-5	Distribution of Columbia River Basalt Group formations	2-8
2-6	General stratigraphic relationship of late-Cenozioc sediments of the Columbia Plateau	2-10
2-7	Structural subdivisions of the Columbia Plateau	2-12
2-8	Geologic structures and features of the Columbia Plateau	2-13
2-9	Historical seismicity of the Columbia Plateau	2-19
2-10	Instrumental seismicity of earthquakes greater than magnitude 3.0 occurring in the Columbia Plateau	2-20
2-11	Earthquakes located by the University of Washington through March 1983	2-22
2-12	Earthquakes located by the University of Washington through March 1983	2-23
2-13	Stereo plots of compression and tension axes derived from focal mechanism solutions.	2-24
2-14	Columbia River drainage basin	2-27
2-15	Hydrologic basins designated for the Columbia Plateau	2-28

LIST OF FIGURES (Continued)

Figure	Title	Page
2-16	Locations of principal dams within the Columbia Plateau study area	2-29
2-17	Three-dimensional perspective views showing the regional potentiometric surface configuration of Saddle Mountains and Wanapum Basalts	2-32
2-18	Three-dimensional perspective views showing the regional potentiometric surfaces for various strata within the Columbia River Basalt Group	2-33
2-19	Locations and vertical head distributions of the State of Washington Department of Ecology test observation wells	2-35
2-20	Sampling sites for ground water collected from Columbia River basalt zones	2-37
2-21	Frequency of well-use types listed in depth intervals for the Pasco Basin	2-43
2-22	Candidate area within the Pasco Basin	2-50
2-23	Subareas within the Pasco Basin	2-51
2-24	Site localities within the Pasco Basin	2-53
2-25	Candidate sites on the Hanford Site	2-55
2-26	Initial candidate sites in the Cold Creek syncline area	2-56
2-27	Candidate sites with three superimposed candidate sites	2-57
2-28	Reference repository location	2-61
2-29	Contour map of reference repository location and boreholes drilled for characterization	2-62
2-30	A composite overlay showing suitable areas for siting of the exploratory shaft	2-63
2-31	General stratigraphy of the reference repository location showing the positions of the proposed candidate horizons	2-66
2-32	Comparison of the proposed candidate horizons ranking results for the deterministic and the probabilistic cases	2-70
3-1	Extent of the Columbia River Basalt Group, Pasco Basin, and reference repository location	3-2

LIST OF FIGURES (Continued)

Figure	Title	Page
3-2	A view of the reference repository location, looking south from Umtanum Ridge Bar	3-3
3-3	Divisions of the Columbia Intermontane Physiographic Province	3-4
3-4	Map of major landform systems of the Pasco Basin	3-5
3-5	Geomorphic map of the reference repository location	3-7
3-6	Stratigraphic units present in the Pasco Basin	3-9
3-7	Key boreholes in and around the reference repository location	3-11
3-8	Generalized geologic cross section through the reference repository location	3-14
3-9	Isopach map of Sentinel Bluffs sequence	3-16
3-10	Paleomagnetic data from Grande Ronde Basalt in borehole RRL-2	3-18
3-11	Isopach map of Cohassett flow	3-19
3-12	Cohassett flow total thickness ranging from 73 to 81 meters within the reference repository location	3-20
3-13	Isopach map of Cohassett flow top	3-21
3-14	Isopach map of the total flow interior of the Cohassett flow	3-23
3-15	Isopach map of the internal vesicular zone in the Cohassett flow	3-24
3-16	Distribution of Ringold Formation section types	3-39
3-17	Suprabasalt stratigraphy in the reference repository location	3-40
3-18	Top of the Ringold Formation	3-42
3-19	Generalized geologic structure map of central Columbia Plateau	3-44
3-20	Top-of-basalt structure contour map with geophysical features	3-61

LIST OF FIGURES (Continued)

Figure	Title	Page
3-21	Magnitude of smallest earthquake detectable by area	3-68
3-22	Earthquakes less than 4 kilometers deep within 10 kilometers of the reference repository location from 1969 through March 1983	3-69
3-23	Earthquakes greater than 4 kilometers deep within 10 kilometers of the reference repository location from 1969 through March 1983	3-70
3-24	Surface-water bodies, including ephemeral creeks, on the Hanford Site	3-74
3-25	Flooded area during the 1894 flood	3-77
3-26	Flooded area from a 100-year flood of the Yakima River in the vicinity of the Hanford Site	3-79
3-27	Flooded area for the probable maximum flood	3-80
3-28	Flooded area resulting from a 50-percent breach of Grand Coulee Dam	3-81
3-29	Extent of probable maximum flood in Cold Creek area	3-84
3-30	Inundation of the Columbia River along the Hanford reach resulting from operation of the proposed Ben Franklin Dam . . .	3-85
3-31	Predicted water-table rise, in sediments overlying the basalts, for proposed Ben Franklin Dam	3-86
3-32	Projected demand for water in the Pasco Basin	3-89
3-33	Surface-water intakes from the Columbia River in the Pasco Basin and vicinity	3-90
3-34	Location map for selected boreholes	3-98
3-35	Hypothetical composite cross section of possible geologic features in a layered basalt sequence	3-115
3-36	Alternative concepts for ground-water movement based on anistropy contracts and hypothetical structures	3-123
3-37	Map of the Hanford Site	3-127
3-38	Major vegetation types on the Hanford Site	3-140

LIST OF FIGURES (Continued)

Figure	Title	Page
3-39	Locations of major plant communities within the reference repository location	3-141
3-40	Wind roses for the Hanford Telemetry Network	3-156
3-41	Monthly wind roses for the Hanford Meteorological Station based on 15.2-meter wind data, 1955 through 1980	3-158
3-42	Probability that the first hourly observation of an inversion will mark the beginning of an inversion run of N hours	3-161
3-43	Major rail lines providing access to the Tri-Cities, Washington	3-166
3-44	Major interstate highways providing access to the Tri-Cities, Washington	3-169
3-45	Local and regional highway network linking the Tri-Cities with major interstate highways	3-170
3-46	Transportation network within the Hanford Site	3-176
3-47	Distribution of residential population in an 80-kilometer radius of the Hanford Meteorological Station by population grid sector for 1980	3-180
3-48	Population trends for Benton and Franklin counties: 1965 to 1984	3-181
3-49	Population trends for cities near the Hanford Site: 1965 to 1984	3-182
3-50	Work force and total employment in Benton and Franklin counties: 1965 to 1984	3-189
3-51	Locations of reservations of affected Indian Tribes	3-209
3-52	Ceded lands and reservations of affected Indian Tribes	3-210
4-1	Development of a subsurface geohydrologic model	4-3
4-2	Drilled shaft concept	4-11
4-3	Conceptual arrangement of the exploratory shaft underground facilities	4-12

LIST OF FIGURES (Continued)

Figure	Title	Page
4-4	Sequences of site-characterization activities used to determine air-quality impacts	4-28
5-1	Illustration of the repository facilities based on the 1982 conceptual design	5-13
5-2	Generalized emplacement process based on the 1982 conceptual design	5-14
5-3	Waste-handling facility based on the 1982 conceptual design	5-15
5-4	Underground repository layout based on the 1982 conceptual design	5-16
5-5	Transporter in emplacement operation based on the 1982 conceptual design	5-17
5-6	Surface facilities plan for the central process area based on the 1982 conceptual design	5-18
5-7	Typical cross section of waste package consolidated light water reactor fuel pins	5-36
5-8	Typical plan view for waste emplacement	5-37
5-9	Cutaway showing waste package emplacement sequence	5-38
5-10	Operating period for construction, operation, and retrieval	5-44
5-11	Socioeconomic impact assessment framework	5-79
5-12	Employment and population projections in the study region	5-81
6-1	1980 census populations for cities within an 80-kilometer radius of the Hanford Meteorological Station	6-12
6-2	Location of existing and planned commercial nuclear reactors and storage facilities with light water reactor commercial spent fuel	6-64
6-3	Location map for selected boreholes	6-91
6-4	Sodium and chloride concentrations for the Hanford Site and Columbia Plateau	6-96

LIST OF FIGURES (Continued)

Figure	Title	Page
6-5	Repository emplacement room flexibility of the Cohassett flow	6-128
6-6	Inferred generalized margin of Cordilleran ice sheet and glacial lakes approximately 12,000 plus or minus 1,000 years before present	6-143
6-7	Preclosure repository thickness criteria	6-192
6-8	Rock-support categories relevant to design range and extreme value qualities for the Cohassett flow	6-202
6-9	Geodril Rig No. 32 large-diameter shaft evaluation	6-214
6-10	Explosibility curve for methane	6-222
6-11	Methane concentrations found in air returns of gassy and nongassy mines	6-223
6-12	Stochastic approach for parameters applied to subsystem performance assessment	6-275
6-13	Waste package subsystem release-rate requirement of 10 CFR 60	6-280
6-14	Probability curves for failure of a typical container	6-284
6-15	Conceptual model used in the estimation of fractional release from a single typical waste package	6-287
6-16	Maximum fractional radionuclide-release rates of iodine-129 at the waste package subsystem boundary	6-291
6-17	Maximum fractional radionuclide-release rates of selenium-79, carbon-14, radium-226, technetium-99, and tin-126 at the waste package subsystem boundary	6-292
6-18	Maximum fractional radionuclide-release rates of neptunium-237, plutonium-239, -240, and -242, and americium-241 at the waste package subsystem boundary	6-293
6-19	Cumulative release of iodine-129, carbon-14, plutonium-239 and -240, and selenium-79 at the waste package subsystem boundary	6-296
6-20	Cumulative release of technetium-99, radium-226, tin-126, americium-241, plutonium-242, and neptunium-237 at the waste package subsystem boundary	6-297

LIST OF FIGURES (Continued)

Figure	Title	Page
6-21	Cumulative release of all significant radionuclides at the waste package subsystem boundary	6-298
6-22	Cumulative release of all radionuclides during 10,000 years at the repository seals subsystem boundary for various median values of hydraulic conductivity in the damaged rock zone	6-305
6-23	Depiction of ground-water flow regimes in models for analyzing pre-waste-emplacement travel times	6-310
6-24	Probability distribution of ground-water travel times for 0-kilometer log-transmissivity correlation range, model 4	6-316
6-25	Probability distribution of ground-water travel times for 2-kilometer log-transmissivity correlation range, model 4	6-317
6-26	Probability distribution of ground-water travel times for 5-kilometer log-transmissivity correlation range, model 4	6-318
6-27	Hypothetical probability distribution function	6-320
6-28	Ground-water travel-time distribution for cumulative release analysis	6-323
6-29	Cumulative radionuclide release during 10,000 years from the site subsystem to the accessible environment	6-326
6-30	Cumulative radionuclide release during 100,000 years from the site subsystem to the accessible environment	6-327
6-31	Cumulative radionuclide release during 10,000 years from the site subsystem to the accessible environment	6-328
6-32	Cumulative radionuclide release during 100,000 years from the site subsystem to the accessible environment	6-329
7-1	Sites selected for nomination	7-2

7 0 1 6 8 0 1 0 5 9

LIST OF TABLES

Table	Title	Page
2-1	Range in concentration and mean composition of major chemical constituents within ground water of the Columbia River Basalt Group	2-38
2-2	Distribution of wells according to major-use categories within the Columbia Plateau and Pasco Basin	2-41
2-3	Distribution of wells within the Columbia Plateau and Pasco Basin according to use	2-42
2-4	Ground-water use in the Pasco Basin	2-44
2-5	Ordinal dominance analysis results	2-60
2-6	Evaluation of summary findings at the reference repository location with respect to the disqualifying conditions	2-73
3-1	Means of major oxides of the proposed candidate horizons in Grande Ronde Basalt	3-17
3-2	Primary fracture abundance and breaks per meter for intraflow structures of the Cohassett flow in core hole samples from McGee well and borehole DC-16A	3-27
3-3	Average chemical composition of flows from the Wanapum and Saddle Mountains Basalts, Pasco Basin	3-30
3-4	Paleomagnetic polarity of Wanapum Basalt and Saddle Mountains Basalt	3-31
3-5	Characteristics of folds and faults within or near the Pasco Basin	3-46
3-6	Seismic events in and near the reference repository location	3-72
3-7	The 1975 water-use totals and composition for Benton and Franklin Counties as a percentage of the State of Washington totals	3-87
3-8	Summary of downstream surface-water uses for the Columbia River	3-91
3-9	Vertical hydraulic head gradients calculated from observed water levels in piezometer cluster DC-19 for March 1985	3-100

LIST OF TABLES (Continued)

Tables	Title	Page
3-10	Vertical hydraulic head gradients calculated from observed water levels in piezometer cluster DC-20 for March 1985	3-101
3-11	Vertical hydraulic head gradients calculated from observed water levels in piezometer cluster DC-22 for March 1985	3-102
3-12	Hydraulic head changes in basalt flow tops and sedimentary interbeds monitored in boreholes DC-19, -20, and -22	3-103
3-13	Comparison of observed hydraulic head gradients for selected basalt flows in the Wanapum and Grande Ronde Basalts	3-105
3-14	Observed hydraulic head gradients and azimuths as determined from three points in the reference repository location	3-106
3-15	Range of concentration and mean compositions of major inorganic constituents of basalt ground waters	3-111
3-16	Comparison of hydrologic properties from boreholes DC-7 and DC-8 tests in the McCoy Canyon flow top of the Grande Ronde Basalt	3-118
3-17	Reactor status summary	3-130
3-18	Mammal species, excluding that observed on the Hanford Site . .	3-143
3-19	Principal bird species observed on the reference repository location	3-144
3-20	Average annual radionuclide concentrations in Columbia River water upstream from the Hanford Site	3-149
3-21	Average annual radionuclide concentrations in Columbia River water downstream from the Hanford Site	3-150
3-22	Columbia River water-quality data for 1984	3-151
3-23	National and State ambient air-quality standards and local background concentrations	3-162
3-24	Annual average daily traffic volumes for 1983	3-172
3-25	Washington and Oregon highway accident statistics	3-173
3-26	Population of Benton and Franklin counties: 1965 to 1984 . . .	3-178

LIST OF TABLES (Continued)

Tables	Title	Page
3-27	Population of cities near the Hanford Site: 1965 to 1984 . . .	3-179
3-28	Population density for cities in the bi-county area near the Hanford Site: 1960 to 1983	3-184
3-29	Work force, employment, and unemployment in Benton and Franklin counties: 1965 to 1984	3-185
3-30	Employment by selected industry groups in Benton and Franklin counties: 1967 to 1982	3-187
3-31	Comparison between average annual percentage rates of change in population and housing units: 1965 to 1981	3-191
3-32	Number of housing units in Benton and Franklin Counties: 1973 to 1984	3-192
3-33	Tri-Cities housing vacancies: 1975 to 1983	3-193
3-34	Municipal water supply and consumption for the Tri-Cities: 1984	3-195
3-35	Waste-water-treatment facilities for the Tri-Cities: 1984 . .	3-196
3-36	Law enforcement personnel and vehicles: 1984	3-197
3-37	School enrollment and building capacity: September 1984 . . .	3-199
3-38	Age composition of males and females in Benton and Franklin Counties and the State of Washington	3-201
3-39	Population by race, ethnic group, and minority status for Benton and Franklin Counties and State of Washington . . .	3-203
3-40	Selected social characteristics of Benton and Franklin Counties and the State of Washington: 1980	3-204
3-41	Selected social characteristics of the Tri-Cities: 1980 . . .	3-204
3-42	Comparison between average rates of increase in population, revenues, and expenditures: 1975 to 1981	3-206
4-1	Summary of expected effects on native biota from Basalt Waste Isolation Project site-characterization activities . . .	4-24
4-2	Northwest regional electric power projections	4-31
4-3	Summary of maximum annual emissions from internal combustion engines during site-characterization activities	4-31

LIST OF TABLES (Continued)

Tables	Title	Page
4-4	Estimates of particulate emissions including fugitive dust releases during the third year of site characterization	4-32
4-5	Potential increases in pollutant concentrations resulting from site-characterization activities	4-34
4-6	Projected peak staffing for site characterization	4-37
4-7	Estimated equipment and material requirements by activity and fiscal year	4-39
5-1	Comparison of alternative repository design concepts	5-4
5-2	Approximate manpower requirements based on the 1982 conceptual design	5-11
5-3	Comparison of requirements and results for design concept development activities	5-24
5-4	Design comparisons of waste-emplacement features	5-27
5-5	Design comparisons of geomechanical data	5-28
5-6	Design comparisons of ventilation requirements	5-29
5-7	Design comparisons of physical dimensions	5-32
5-8	Design comparisons of ventilation features	5-33
5-9	Waste package characteristics	5-39
5-10	Summary of expected effects on the physical environment from construction and operation of a repository at the Hanford Site	5-46
5-11	Summary of expected effects on native biota from construction and operation of a repository at the Hanford Site	5-49
5-12	Source quantities of nonradiological pollutants	5-53
5-13	Maximum annual ground-level pollutant concentrations	5-55
5-14	Maximum short-term ground-level pollutant concentrations	5-57
5-15	Projected total nuclear waste cask shipments to a repository at the Hanford Site	5-62

7 0 1 6 8 0 1 0 6 3

LIST OF TABLES (Continued)

Tables	Title	Page
5-16	Projected average daily waste cask shipments to a repository at the Hanford Site	5-64
5-17	Regional population density data along highway routes to the Hanford Site	5-70
5-18	Transportation risk projections, 100-percent truck transport, 100 percent via regional northern route	5-71
5-19	Transportation risk projections, 100-percent truck transport, 100 percent via regional southern route	5-72
5-20	Regional population density data along railroad routes to the Hanford Site	5-74
5-21	Transportation risk projections, 100-percent rail transport, 100 percent via regional northern route	5-75
5-22	Transportation risk projections, 100-percent rail transport, 100 percent via regional southern route	5-76
5-23	Projected baseline population and repository impact: 1990 to 2010	5-86
6-1	Summary of positive findings resulting from the application of the General Siting Guidelines to the reference repository location	6-6
6-2	Population within the general vicinity of the reference repository location	6-14
6-3	Application of major Federal environmental laws to the reference repository location on the Hanford Site	6-33
6-4	Summary of ground-water travel-time estimates from modeling studies	6-79
6-5	Potential geologic or climatologic processes and their hydrologic effects	6-82
6-6	Comparison of observed hydraulic head gradients for selected basalt flows in the Wanapum and Grande Ronde Basalts	6-90
6-7	Thermal properties of selected flows from the Columbia River Basalt Group at the Hanford Site	6-131
6-8	Thermal properties of selected rock types	6-132
6-9	Thermal properties of generic rock types	6-133

LIST OF TABLES (Continued)

Tables	Title	Page
6-10	Age of glacial terminations--summary of published estimates	6-142
6-11	Comparison of repository size requirements for different in-situ stress magnitudes within the reference repository location	6-191
6-12	Thickness data for the Cohassett flow relative to other thick Grande Ronde Basalt flows	6-194
6-13	Mean interior thickness and standard deviation for four Grande Ronde Basalt flows	6-195
6-14	Rock mechanics characteristics of the Cohassett flow vesicular zone	6-196
6-15	Geomechanics classification of repository excavations in the Cohassett flow	6-199
6-16	Rock mass quality classification of repository excavation in the Cohassett flow	6-200
6-17	Recommended roof reinforcement	6-201
6-18	Comparisons of deep, highly stressed excavations	6-204
6-19	Evidence of constructibility as compared to planned shaft construction	6-208
6-20	Comparison of relevant large-diameter shafts to the Basalt Waste Isolation Project proposed repository shafts	6-212
6-21	Case histories of steel and composite liners	6-216
6-22	Underground operations using refrigerated-assisted ventilation air for cooling	6-224
6-23	Rock burst case history comparison with expected repository conditions	6-235
6-24	Data set for assessment of waste package subsystem performance	6-286
6-25	Radionuclide data set for assessment of waste package subsystem performance	6-289
6-26	Transport property data set for assessment of waste package subsystem performance	6-290

7 0 1 6 8 0 1 0 6 5

LIST OF TABLES (Continued)

Tables	Title	Page
6-27	Fractional radionuclide-release rates at the waste package subsystem boundary at 90-percent probability	6-295
6-28	Cumulative radionuclide-release rates at the waste package subsystem boundary at 90-percent probability	6-299
6-29	Data set for assessment of the repository seals subsystem . . .	6-303
6-30	Mean cumulative release of all radionuclides at the repository seals subsystem boundary during 10,000 years	6-306
6-31	Parameter field probability distributions for pre-waste-emplacement ground-water travel-time model	6-313
6-32	Stratigraphic layers and thicknesses for pre-waste-emplacement ground-water travel-time models	6-315
6-33	Principal input-output information for analysis of cumulative radionuclide release from the site subsystem	6-321
6-34	Potential disruption scenarios identified by means of a Delphi survey	6-336
7-1	Guideline-condition findings by major consideration--geohydrology	7-5
7-2	Guideline-condition findings by major consideration--geochemistry	7-18
7-3	Guideline-condition findings by major consideration--rock characteristics (postclosure)	7-25
7-4	Guideline-condition findings by major consideration--climatic change	7-30
7-5	Guideline-condition findings by major consideration--erosion	7-34
7-6	Guideline-condition findings by major consideration--dissolution	7-38
7-7	Guideline-condition findings by major consideration--tectonics (postclosure)	7-41
7-8	Guideline-condition findings by major consideration--natural resources	7-46

LIST OF TABLES (Continued)

Tables	Title	Page
7-9	Guideline-condition findings by major consideration--population density and distribution	7-56
7-10	Guideline-condition findings by major consideration--site ownership and control (preclosure)	7-60
7-11	Guideline-condition findings by major consideration--meteorology	7-63
7-12	Guideline-condition findings by major consideration--offsite installations and operations	7-67
7-13	Guideline-condition findings by major consideration--environmental quality	7-73
7-14	Guideline-condition findings by major consideration--socioeconomics	7-80
7-15	Guideline-condition findings by major consideration--transportation	7-90
7-16	Transportation risk summary	7-96
7-17	Factors used to evaluate disruption of the environment and cost of infrastructure	7-97
7-18	Guideline-condition findings by major consideration--surface characteristics	7-107
7-19	Guideline-condition findings by major consideration--rock characteristics (preclosure)	7-111
7-20	Guideline-condition findings by major consideration--rock	7-118
7-21	Guideline-condition findings by major consideration--tectonics	7-123
7-22	Repository cost estimates	7-128
7-23	Salt repository cost estimates	7-132
7-24	Basalt repository cost estimates	7-136
7-25	Tuff repository cost estimates	7-139

CHAPTER 6 SUMMARY

Chapter 6 addresses the suitability of the reference repository location for site characterization and for development as a repository. The discussion is presented according to the requirements of the Nuclear Waste Policy Act of 1982 and the General Siting Guidelines (DOE, 1984a). Some guidelines discussed in Chapter 6 require information to be developed during site characterization (e.g., from borehole drilling and hydrologic testing) before compliance can be demonstrated; others do not. Section 6.1 presents the rationale for distinguishing between guidelines that do or do not require site characterization.

Section 6.2 deals with qualifying guidelines that do not require site characterization (e.g., the guideline on site ownership and control). The narrative associated with this particular guideline notes that the reference repository location is on the Hanford Site in the State of Washington, which has been under Federal control for over 40 years. Many of its attributes that led to its original selection as a Federal nuclear defense site also support its potential suitability as a repository site.

Section 6.3 deals with guidelines that require site characterization (e.g., the guideline on geohydrology). The narrative associated with this guideline notes that additional field and laboratory measurements would be needed as input to numerical simulation models to achieve the desired level of confidence required to reach a conclusion on the qualifying condition. Thus, in the absence of site-characterization data, the conclusions reached on individual guidelines in Section 6.3, are, for the most part, preliminary in nature.

The narrative for each guideline in this chapter is defined by the General Siting Guidelines and follows the order presented below.

- A restatement of the qualifying condition.
- A description of the guideline evaluation process.
- Statements of favorable conditions, potentially adverse conditions, and (when present) disqualifying conditions.
- A conclusion on the qualifying condition evaluates the composite favorability of each qualifying statement. These preliminary conclusions also discuss the uncertainty of meeting each qualifying condition.

Tables 6-A and 6-B list the conclusions on the ability of the reference repository location to meet the qualifying conditions. Because discussions of these conditions frequently refer the reader to sections containing related information in previous chapters, Table 6-C presents a cross-reference matrix of such sections.

Table 6-A. Qualifying conditions that do not require site characterization (sheet 1 of 2)

Qualifying condition	Current compliance status
Technical guidelines	
Site ownership and control (both guidelines)	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition is met, since the reference repository location is owned by the Federal Government and controlled by the U.S. Department of Energy.
Population density and distribution	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition appears to be met as a result of low Hanford Site population densities, low regional population densities, and low projected offsite radiation doses.
Meteorology	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition appears likely to be met due to the remoteness of the site and atmospheric dispersion characteristics.
Offsite installations and operations	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition appears likely to be met, based on analyses of radionuclide releases from nearby installations and operations.
Environmental quality	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition appears likely to be met by complying with applicable environmental regulations.
Socioeconomic impacts	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition is met, since there are no significant projected adverse social or economic impacts on nearby communities.
Transportation	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition is met for transportation of radioactive waste to the reference repository location, because the local Hanford transportation network provides ready access to major rail and highway corridors.

Table 6-A. Qualifying conditions that do not require site characterization (sheet 2 of 2)

Qualifying condition	Current compliance status
Preclosure systems guidelines	
Radiological safety	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition appears to be met, based on site remoteness, low population density adjacent to the reference repository location, and very low projected radiation exposure to the general public.
Environmental quality, socioeconomics, and transportation	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This condition is met, based on environmental, socioeconomic, and transportation considerations.

NOTE: Definition of the various compliance levels (e.g., 1, 2, 3, 4) can be found in Appendix B.

See Table 6-C for sections related to Chapter 6 discussions.

See Table 6-1 for cross references to the General Siting Guidelines (DOE, 1984a).

Table 6-B. Qualifying conditions that require site characterization (sheet 1 of 2)

Qualifying condition	Current compliance status
Geohydrology	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Evidence appears to support a preliminary finding that the reference repository location could meet this condition, although uncertainty exists.
Geochemistry	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Evidence suggests a finding that the reference repository location meets this condition.
Rock characteristics (preclosure and postclosure)	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The reference repository location appears likely to meet this condition, based on the expected characteristics of the host rock, although uncertainty exists.
Climatic changes	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Significant changes in climatic conditions are not expected to occur over the next 10,000 years; therefore, the reference repository location is likely to meet this condition.
Erosion	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition (Level 4). Erosional processes are not expected to result in radionuclide releases at the reference repository location; therefore, this condition is met.
Dissolution	The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition (Level 4). Dissolution features are not present in basalt; therefore, this condition is met at the reference repository location.
Tectonics (preclosure and postclosure)	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The reference repository location appears likely to meet this condition, based on the expected tectonic processes and events, although uncertainty exists.
Natural resources	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Natural resources are generally scarce at or near the reference repository location; therefore, this condition appears to be met.

Table 6-B. Qualifying conditions that require site characterization (sheet 2 of 2)

Qualifying condition	Current compliance status
Surface characteristics	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The reference repository location meets this condition, since it is located on well-drained, generally flat terrain, although flash flooding could occur.
Hydrology	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The reference repository location appears to meet this condition, since technology is available for repository construction, operation, and closure.
Preclosure system guideline (costs)	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The reference repository location appears to meet this condition, since reasonable technology is available and current cost estimates between sites are comparable within uncertainty levels.
Postclosure system guideline	The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The natural and engineered barrier systems at the reference repository location are likely to achieve compliance with this condition within uncertainty levels.

NOTE: Definition of the various compliance levels (e.g., 1, 2, 3, 4) can be found in Appendix B.

See Table 6-C for sections related to Chapter 6 discussions.

See Table 6-1 for cross references to the General Siting Guidelines (DOE, 1984a).

Table 6-C. Sections related to Chapter 6 discussions (sheet 1 of 2)

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	Chapter 6
Qualifying conditions that do not require site characterization					6.2
Site ownership and control		3.4.1	4.2.2.6	5.2.3.6	6.2.1.1/6.2.1.3
Population density and distribution	2.3.6*	3.6.1	4.2.2.1	5.2.3.1	6.2.1.2
Meteorology		3.4.3	4.1.2.4		6.2.1.4
Offsite installations and operations	2.3.7*				6.2.1.5
Environmental quality	2.3.8*	3.4	4.1.2.3/4.2.1.3	5.2.1.3	6.2.1.6
Socioeconomic impacts	2.3.9*	3.6	4.1.2.2/4.2.2	5.2.3	6.2.1.7
Transportation		3.5	4.2.3	5.2.2/5.1.7	6.2.1.8
Preclosure systems guideline (radiological safety)					6.2.2.1
Preclosure systems guideline (environmental, socioeconomic, and transportation)					6.2.2.2

Table 6-C. Sections related to Chapter 6 discussions (sheet 2 of 2)

	Chapter 2	Chapter 3	Chapter 4	Chapter 5	**Chapter 6**
Qualifying conditions that require site characterization					6.3
Geohydrology	2.1.1/2.3.1 (2.1.3/2.1.4)	3.3	4.2.1.2	5.2.1.2	6.3.1.1
Geochemistry			4.1.2.6		6.3.1.2
Rock characteristics	2.3.10*				6.3.1.3/6.3.3.2
Climatic changes					6.3.1.4
Erosion	2.3.2*				6.3.1.5
Dissolution	2.3.3*				6.3.1.6
Tectonics	2.1.2/2.3.4/2.3.12*	3.2.3	4.1.1.2		6.3.1.7/6.3.3.4
Human interference (natural resources)	2.3.5*				6.3.1.8
Surface characteristics					6.3.3.1
Hydrology	2.1.3/2.1.4/2.3.11*	3.3	4.1.1.7/4.2.1.2	5.2.1.2	6.3.3.3
Postclosure system guidelines					6.3.2
Preclosure system guideline (ease and cost of construction)					6.3.4
Preliminary performance assessment					6.4

*Disqualifier analysis.

Section 6.4 provides an overview of the analytical methods used by the U.S. Department of Energy to provide a preliminary assessment of site suitability. These methods identify sensitive parameters or areas (e.g., waste isolation, safety, and related functions) that require further analysis during site characterization. The methods help define activities of the U.S. Department of Energy that will identify and mitigate problems in areas important to safety or the performance of the repository. This section is divided into preclosure performance assessment and postclosure performance assessment.

The preliminary postclosure performance assessment evaluates the long-term performance of the reference repository at the Hanford Site on the basis of mathematical models and site data. The mathematical models estimate the effectiveness of the isolation system, primarily in terms of the subsystems performance (i.e., waste package, repository seals, and site).

Preliminary performance assessments are presented for two time periods: 10,000 and 100,000 years. Also, the mathematical models predict the long-term performance for two cases: A reference case, which reflects expected conditions and behavior of the systems; and the performance limits case, which reflects only a minimum level of isolation performance by the engineered barriers (waste package and repository seals). The above probabilistic analyses indicate ground-water travel time to the accessible environment, potential radionuclide release rates from the engineered system, and cumulative potential radionuclide releases at the accessible environment.

There is no evidence to suggest that the reference repository location is not disqualified under the General Siting Guidelines (DOE, 1984a) or that the reference repository location would not meet the qualifying conditions associated with the General Siting Guidelines.

Chapter 6

SUITABILITY OF THE HANFORD SITE FOR SITE CHARACTERIZATION AND FOR DEVELOPMENT AS A REPOSITORY

The Nuclear Waste Policy Act of 1982 requires that the environmental assessment include a statement of the basis for nominating a site as suitable for characterization. This statement is an evaluation of site suitability under the U.S. Department of Energy General Siting Guidelines (DOE, 1984a); the evaluation is the basis for the comparison of sites reported in Chapter 7. Such an evaluation for the reference repository location is presented in this chapter.

6.1 THE U.S. DEPARTMENT OF ENERGY SITING GUIDELINES

As directed by Section 112 of the Nuclear Waste Policy Act of 1982, the U.S. Department of Energy has developed general guidelines for siting geologic repositories. These guidelines have been published as 10 CFR 960 (DOE, 1984a). They are to be used in the site-selection process for the first repository: The nomination of at least five sites as suitable for characterization, the recommendation of three sites for characterization, and the recommendation of one site for development as a repository.

6.1.1 FORMAT AND STRUCTURE OF THE GUIDELINES

The siting guidelines are divided into implementation, postclosure, and preclosure. The implementation guidelines are not directly used in the evaluation of sites; their purpose is to specify how the postclosure and preclosure guidelines are to be applied in site screening and selection. The postclosure guidelines govern the siting considerations that deal with the long-term behavior of a repository; that is, its behavior after waste emplacement and repository closure. These are the considerations most important for ensuring the long-term protection of the health and safety of the public. The preclosure guidelines govern the siting considerations that deal with protecting the public and the repository workers from exposure to radiation and other operating hazards. They are also important considerations in protecting environmental quality and in mitigating socioeconomic impacts, because environmental and socioeconomic effects of a repository will occur during construction and operation.

The postclosure and preclosure guidelines are subdivided into system and technical guidelines. The postclosure system guideline defines general requirements for the performance of the repository system after closure. These requirements are based generally on the objectives of protecting public health and safety; they are based specifically on the standards released by the U.S. Environmental Protection Agency as

40 CFR 191 (EPA, 1985) and the criteria promulgated by the U.S. Nuclear Regulatory Commission in 10 CFR 60 (NRC, 1985a). The postclosure technical guidelines specify requirements for one or more elements of the repository system (the physical properties and physical phenomena at the site).

The three preclosure system guidelines state broad requirements for three different systems. These systems include, in addition to characteristics of the site and engineered components, the people and the environment near the site. The elements of these systems are defined in the supplementary information preceding the guidelines. Each of the preclosure technical guidelines specifies requirements on one or more of these elements.

The postclosure and preclosure technical guidelines specify conditions that would qualify and disqualify sites and they specify conditions that would be considered favorable or potentially adverse.

A qualifying condition is contained in each technical guideline. Taken together, these qualifying conditions are the minimum conditions for site qualification. A site will be qualified only if it meets all of the qualification conditions. A site will be disqualified if site characterization shows that it fails to meet any one of the qualifying conditions. Failure to meet a qualifying condition can usually be determined only after site characterization and the concurrent investigations of environmental and socioeconomic conditions. Qualifying conditions are generally stated in terms of specifications that require analyses of the repository system, and data for such analyses will be available only at the completion of site characterization and investigation. Before site characterization, however, evaluations that compare sites will reveal the relative potential of those sites to meet the qualifying conditions.

Disqualifying conditions are contained in 12 technical guidelines. Each describes a condition that is considered so adverse as to constitute sufficient evidence to conclude, without further consideration, that a site is disqualified. Many of the 17 disqualifying conditions pertain to conditions whose presence may be verifiable at a site without extensive data gathering or complex analysis.

The favorable and potentially adverse conditions can be used to assess the suitability of a site before detailed studies have been performed. They provide preliminary indications of system performance. Although favorable conditions need not exist at a given site to meet the qualifying condition, the existence of such conditions leads to an expectation that subsequent evaluations will yield enhanced confidence in a site's suitability. Similarly, the purpose of determining whether any potentially adverse conditions exist at a site is to provide an early indication of conditions that must be examined carefully before judging the acceptability of that site. Such examinations must evaluate the effects of other, possibly compensatory, conditions present at a site.

Thus, a site that has most of the favorable conditions can be presumed likely to meet the system guidelines, while a site with many potentially adverse conditions can be considered to have a much greater degree of uncertainty in meeting the system guidelines.

6.1.2 USE OF THE SITING GUIDELINES IN EVALUATING SITE SUITABILITY

The evaluations of site suitability provide the basis for making the findings that Appendix III of the General Siting Guidelines (DOE, 1984a) requires for disqualifying and qualifying conditions. Using the term "apply" to mean to evaluate a condition and make a finding of compliance, Appendix III specifies how the guidelines are to be applied at the principal decision points of the siting process: (1) Identification as potentially acceptable, (2) nomination as suitable for characterization or recommendation for characterization, and (3) recommendation for development as a repository. In particular, Appendix III specifies the types of findings that are to result from the application of the disqualifying conditions and the qualifying conditions. Two levels of findings, one showing an increased level of confidence over the other, are specified for the disqualifying and the qualifying conditions.

For the disqualifying conditions, a level 1 finding means that the evidence does not (or, conversely, does) support a finding that the site is disqualified. A level 2 finding is a higher level finding requiring greater confidence and more extensive supporting data. A level 2 finding means that the evidence supports a finding that the site is not disqualified on the basis of existing evidence and is not likely to be disqualified (or that the site is disqualified or is likely to be disqualified).

For the qualifying conditions, a level 3 finding means that the evidence does not (or, conversely, does) support a finding that the site is not likely to meet the qualifying condition. A level 4 finding, which is the higher level finding, means that the evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition (or that the site cannot meet the qualifying condition and is unlikely to be able to meet it).

For a site to be nominated, at least a positive level 1 finding must be made for each disqualifying condition, and at least a positive level 3 finding must be made for each qualifying condition. For a site to be recommended for development as a repository, a level 2 finding must be made and supported for each disqualifying condition, and a level 4 finding must be made and supported for each qualifying condition.

In conducting the suitability evaluations for the site, the higher level finding was made wherever the evidence supported it. Most often, however, the available data were inadequate for supporting the higher level findings, which must wait for the results of site characterization and investigations, as well as for the final design of the repository.

An identification of the favorable conditions and potentially adverse conditions present at the site is necessary for evaluating the ability of the site to meet the individual qualifying conditions. Before site characterization, that ability is determined largely by examining the balance between those conditions along with information on the repository system. The identification of the favorable and potentially adverse conditions as present or not present at the site is based on data existing for the site or conservative assumptions when the existing data are inadequate for the identification. (Conservative assumptions are those that reduce the possibility that later findings will prove the assumptions to be wrong.) For a favorable condition to be claimed as present, it is necessary for the data and conservative assumptions to support that conclusion clearly. Otherwise, the favorable condition is stated to be not present. Similarly, a potentially adverse condition is stated to be present unless the data and the conservative assumptions clearly support a conclusion that the condition is not present.

The process of making suitability evaluations and arriving at findings for the disqualifying and qualifying conditions is fully discussed and presented in the guideline-by-guideline evaluations in Sections 6.2 and 6.3. The evidence required to support these evaluations includes the types of information specified in Appendix IV of the General Siting Guidelines (DOE, 1984a).

6.1.3 DIVISION OF THE GUIDELINES INTO CATEGORIES

The Nuclear Waste Policy Act of 1982 requires two evaluations of the suitability of a site.

1. An evaluation as to whether a site is suitable for site characterization under the siting guidelines.

2. An evaluation as to whether a site is suitable for development as a repository under each guideline that does not require site characterization as a prerequisite for its application.

For making these evaluations, the guidelines are divided into two categories according to whether they do or do not require site characterization as a prerequisite for their application. The basis for this division of the guidelines is the definition of site characterization in the Nuclear Waste Policy Act of 1982. The Act defines site characterization as activities undertaken to establish the geologic conditions at a candidate site, including borings, surface excavations, exploratory shafts, and in situ testing.

Guidelines not requiring site characterization as a prerequisite to application are those that do not contribute to establishing the geologic conditions at a site. Guidelines in this category are predominantly concerned with surface conditions, and most of them are preclosure guidelines. Information required to establish compliance with these guidelines may be obtained before or during site characterization. Section 6.2 presents evaluations of the reference repository location against the guidelines in this category.

Guidelines requiring site characterization are those that contribute to establishing the geologic conditions at a site. Guidelines in this category are concerned predominantly with subsurface conditions, and most of them are postclosure guidelines. Section 6.3 presents evaluations of the reference repository location against guidelines in this category. Information required to establish compliance with these guidelines would be obtained during site characterization.

Table 6-1 lists the guidelines in each category and shows the levels of positive findings for the reference repository location that were made in accordance with Appendix III of the General Siting Guidelines (DOE, 1984a).

6.1.4 FORMAT FOR THE PRESENTATION OF SITE EVALUATIONS

In Sections 6.2 and 6.3, the presentation of each technical guideline begins with an introduction that states the qualifying condition for that guideline and briefly explains the objectives and structure of the guideline. The introduction is followed by a section that reviews or cites the data available for the evaluations against the guideline, explains the general assumptions that must be made, and discusses data uncertainties. Each favorable, potentially adverse, and disqualifying condition is, in turn, discussed; each discussion evaluates the presence or absence of the condition and states a conclusion based on that evaluation. Finally, the ability of the site to meet the qualifying condition is examined and a conclusion is presented. For the disqualifying and qualifying conditions, the conclusion is presented as a finding corresponding to one of the levels specified by Appendix III of the General Siting Guidelines (DOE, 1984a) (see Section 6.1.2).

The format for presenting the system guidelines is similar, but it omits the discussion of favorable, potentially adverse, and disqualifying conditions because these conditions do not appear in the system guidelines.

The conclusions drawn in these presentations are different in Sections 6.2 and 6.3. Because the guidelines in Section 6.2 do not require site characterization, the conclusion refers to the suitability of the site for development as a repository. Such a conclusion cannot be drawn for guidelines that require site characterization as a prerequisite for their application; only after site characterization can the question of suitability for repository development be addressed. Rather, the appropriate conclusion for these guidelines is whether the site is suitable for further study. The conclusions presented in Section 6.3, therefore, refer only to the suitability of the site for characterization.

Table 6-1. Summary of positive findings resulting from the application of the General Siting Guidelines (DOE, 1984a) to the reference repository location

Guideline		Level of finding	
Number	Title	Disqualifying condition	Qualifying condition
Guidelines that do not require site characterization			
960.4-2-8-2	Human interference (site ownership and control)	(a)	3
960.5-2-1	Population density and distribution	2[b]	3
960.5-2-2	Site ownership and control	(a)	3
960.5-2-3	Meteorology	(a)	3
960.5-2-4	Offsite installations and operations	1	3
960.5-2-5	Environmental quality	2[b]	3
960.5-2-6	Socioeconomic impacts	1	3
960.5-2-7	Transportation	(a)	3
960.5-1(a)(1)	Preclosure radiological safety	(a)	3
960.5-1(a)(2)	Environmental, socioeconomics, and transportation	(a)	3
Guidelines that do require site characterization			
960.4-1	Postclosure system	(a)	3
960.4-2-1	Geohydrology	1	3
960.4-2-2	Geochemistry	(a)	3
960.4-2-3	Rock characteristics	(a)	3
960.4-2-4	Climatic changes	(a)	3
960.4-2-5	Erosion	2	4
960.4-2-6	Dissolution	2	4
960.4-2-7	Tectonics	1	3
960.4-2-8-1	Human interference (natural resources)	1[b]	3
960.5-1(a)(3)	Preclosure system (costs)	(a)	3
960.5-2-8	Surface characteristics	(a)	3
960.5-2-9	Rock characteristics	1	3
960.5-2-10	Hydrology	1	3
960.5-2-11	Tectonics	1	3

NOTE: Definition of the various compliance levels (e.g., 1, 2, 3, 4) can be found in Appendix B.

[a]No disqualifying condition exists for this guideline.

[b]This finding applies to each part of the disqualifying condition.

6.2 SUITABILITY OF THE SITE FOR DEVELOPMENT AS A REPOSITORY; EVALUATION AGAINST THE GUIDELINES THAT DO NOT REQUIRE SITE CHARACTERIZATION

6.2.1 TECHNICAL GUIDELINES

6.2.1.1 Human interference (site ownership and control) (Section 960.4-2-8-2)

"The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in Sections 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness."

6.2.1.1.1 Qualifying condition

"The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1."

6.2.1.1.2 Evaluation process

Lands within the reference repository location have been under the jurisdiction of the Federal Government since 1943 (see Section 3.4.1). The Hanford Site is managed by the U.S. Department of Energy. Two parcels of land within the Hanford Site are leased to the State of Washington and the Washington Public Power Supply System (see Fig. 3-37). The State subleases a portion of its leased land to U.S. Ecology, Inc., for disposal of low-level radioactive wastes. A portion of the State of Washington-leased land is encompassed within the reference repository location, but is not expected to conflict with site-characterization activities and is not in an area where surface or subsurface areas of the repository are currently planned. Use of the leased land is limited to nuclear activities compatible with U.S. Department of Energy activities and is subject to U.S. Department of Energy approval of proposed uses. The U.S. Department of Energy retains the ability to terminate the lease for the unused portions of the leasehold if desired.

The Washington Public Power Supply System-leased land is the site for three nuclear power reactors. The State also retains fee title to a section of land for use as a proposed nonradioactive hazardous waste-disposal site. In addition, the Big Bend Alberta Company owns the mineral rights to several parcels of land within the Arid Lands Ecology Reserve.

The lands designated for the reference repository location (see Fig. 2-28) consist of acquired lands plus the following public domain:

- Township 12 North, Range 25 East of the Willamette Meridian, Section 2, part of Section 4, Section 10, Section 12, and part of Section 14.

- Township 12 North, Range 26 East of the Willamette Meridian, part of Section 4, Section 6, Section 8, and part of Section 18.

- Township 13 North, Range 26 East of the Willamette Meridian, part of Section 32.

Sections 10 and 4, Township 12 North, Range 25 East of the Willamette Meridian have been withdrawn from all forms of appropriation under the public land laws, including the mining and mineral leasing laws, and have been reserved for use by the U.S. Atomic Energy Commission in connection with its Hanford Site operations. The pertinent part of applicable Public Land Order 1273 (BLM, 1956), dated March 4, 1956, reads as follows:

> "Subject to valid existing rights, the following-described public lands in Washington are hereby withdrawn from all forms of appropriation under the public-land laws, including the mining and the mineral-leasing laws, and reserved for use of the Atomic Energy Commission in connection with its Hanford Operations."

All functions of the U.S. Atomic Energy Commission with respect to the Hanford Site and certain other locations have been transferred to the U.S. Department of Energy. As a result, said Sections 10 and 4, Township 12 North, Range 25 East of the Willamette Meridian are under the jurisdiction of the U.S. Department of Energy, which holds that land pursuant to Public Land Order 1273.

The other sections or partial sections of public domain first described above have been withdrawn and reserved for use by the U.S. Atomic Energy Commission and held by it as agent of and on behalf of the United States as provided in Public Law 88-557. That legislation also provides in pertinent part that

> ". . . the Atomic Energy Commission shall exercise all of the authorities with respect thereto as provided in the Atomic Energy Act of 1954, as amended, and the Atomic Energy Community Act of 1955, as amended: Provided, That any disposal of such lands pursuant to such Acts shall be subject to valid existing rights in third parties: Provided further, That nothing herein shall be deemed to add to, modify, or eliminate any authority of the Commission pursuant to such Acts to dispose of property."

As a result of the above-described transfer of functions from the U.S. Atomic Energy Commission to the U.S. Department of Energy, these other sections (other than Sections 10 and 4, Township 12 North, Range 25 East of the Willamette Meridian) or partial sections of public domain are also under the jurisdiction of the U.S. Department of Energy.

Most of the Hanford Site south of the Columbia River is fenced and (or) posted to prohibit access by unauthorized personnel. The State of Washington has an easement through the Hanford Site for Route 240. A portion of Route 240 crosses a corner of the reference repository location (see Fig. 3-37). This easement is fenced on both sides and is patrolled to control access to the Hanford Site (including the proposed location for repository surface facilities). Authorized access to the proposed repository surface facilities can only be gained by passing through one of several security checkpoints.

6.2.1.1.3 Favorable condition

"Present ownership and control of land and all surface and subsurface rights by the DOE."

This favorable condition is present at the reference repository location, since the Federal Government owns and the U.S. Department of Energy controls the land and all mineral rights. No potential impact is foreseen between State of Washington-leased land and site-characterization activities.

The Hanford Site has been under the jurisdiction of the Federal Government since 1943 with the exception of the 1977 transfer of 2.6 square kilometers (1 square mile) of limited surface rights to the State of Washington for a proposed nonradioactive hazardous waste-disposal site. This land is located 9 kilometers (5.5 miles) southeast of the reference repository location (see Fig. 3-37). The lands designated as the reference repository location consist of acquired land plus sections that have been withdrawn from all forms of appropriation under the public land laws (see Subsection 6.2.1.1.2). Present ownership and control of the land and all surface and subsurface mineral rights are by the Federal Government and the U.S. Department of Energy. Current and projected land use associated with U.S. Department of Energy defense facilities in the 200 West Area and State of Washington-leased land are not expected to conflict with potential site-characterization or repository activities (see Subsections 4.2.2.6 and 5.2.3.6).

6.2.1.1.4 Potentially adverse condition

"Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings."

This potentially adverse condition is not present at the reference repository location since the Federal Government owns and the U.S. Department of Energy controls the land under study.

There are no projected land-ownership conflicts. The U.S. Department of Energy controls the land within the boundaries of the reference repository location (see Subsection 6.2.1.1.2).

6.2.1.1.5 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location on the Hanford Site is not likely to meet the site ownership qualifying condition related to human interference (Level 3). Supporting this finding are the following factors.

- Lands within the reference repository location have been under the jurisdiction of the Federal Government since 1943.
- Present ownership and control of the reference repository location and all surface and subsurface mineral rights are by the Federal Government and the U.S. Department of Energy.
- Access to proposed surface facilities of the reference repository location is controlled by the U.S. Department of Energy.

There is little uncertainty associated with this conclusion.

6.2.1.2 <u>Population density and distribution (Section 960.5-2-1)</u>

The objective of the population density and distribution guideline (DOE, 1984a) is to ensure the selection of a repository site that will minimize risk to the public and permit compliance with U.S. Environmental Protection Agency and U.S. Nuclear Regulatory Commission regulations. The U.S. Environmental Protection Agency standard (40 CFR 191; EPA, 1985) limits exposures to members of the public and requires that they be reduced below the limits to the extent reasonably achievable. The U.S. Environmental Protection Agency standard limits the radiation dose that any individual outside the boundary of the restricted area would receive to a maximum yearly dose of 25 millirems to the whole body, 75 millirems to the thyroid, or 25 millirems to any other organ. (Natural background radiation is estimated to be approximately 100 millirems per year for residents near the Hanford Site (Price et al., 1985, p. 57).) The doses that would result from repository releases are lower than the U.S. Environmental Protection Agency maximum permissible doses.

This guideline includes a qualifying condition, two favorable conditions, and two potentially adverse conditions for analysis. It also has one disqualifying condition.

6.2.1.2.1 Qualifying condition

"The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in Section 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limits allowable under the requirements specified in Section 960.5-1(a)(1)."

6.2.1.2.2 Evaluation process

The guideline requires consideration of the (1) population density in the general region of the site, (2) remoteness of the site from highly populated areas, (3) residential, seasonal, or daytime population density within the projected site boundary, (4) proximity of the site to highly populated areas or to areas having at least 1,000 individuals in a 1.6- by 1.6-kilometer (1- by 1-mile) area, and (5) ability to develop an emergency preparedness plan.

Residential population distribution and density data for the general region were obtained from the 1980 census. These data are presented in Figure 3-47 on a 16-sector compass grid, with annular concentric rings every 16 kilometers (10 miles) extending out to 80 kilometers (50 miles). The centroid of the grid is the Hanford Meteorological Station, which is located within the northeast portion of the reference repository location (Fig. 6-1). The population density is low within the region and the site is remote as a result of Federal ownership of large land tracts and the predominant rural agricultural land use surrounding the Hanford Site. Beyond the 16-kilometer (10-mile) radius, extensive farming is carried out along the Yakima River and to the north and east of the Hanford Site on the Columbia Basin Irrigation Project (see Subsection 2.1.3.1). West of the Hanford Site is the U.S. Army Yakima Firing Center and has restricted access on approximately 658 square kilometers (411 square miles). The U.S. Department of Energy and its contractors employ approximately 12,000 workers on the 1,500-square-kilometer (570-square-mile) Hanford Site.

Projections of future population will be done during site characterization. However, Federal ownership of the Hanford Site will limit population growth within a 16-kilometer (10-mile) radius of the Hanford Meteorological Station during repository operation. This reduces the uncertainty associated with projected population growth.

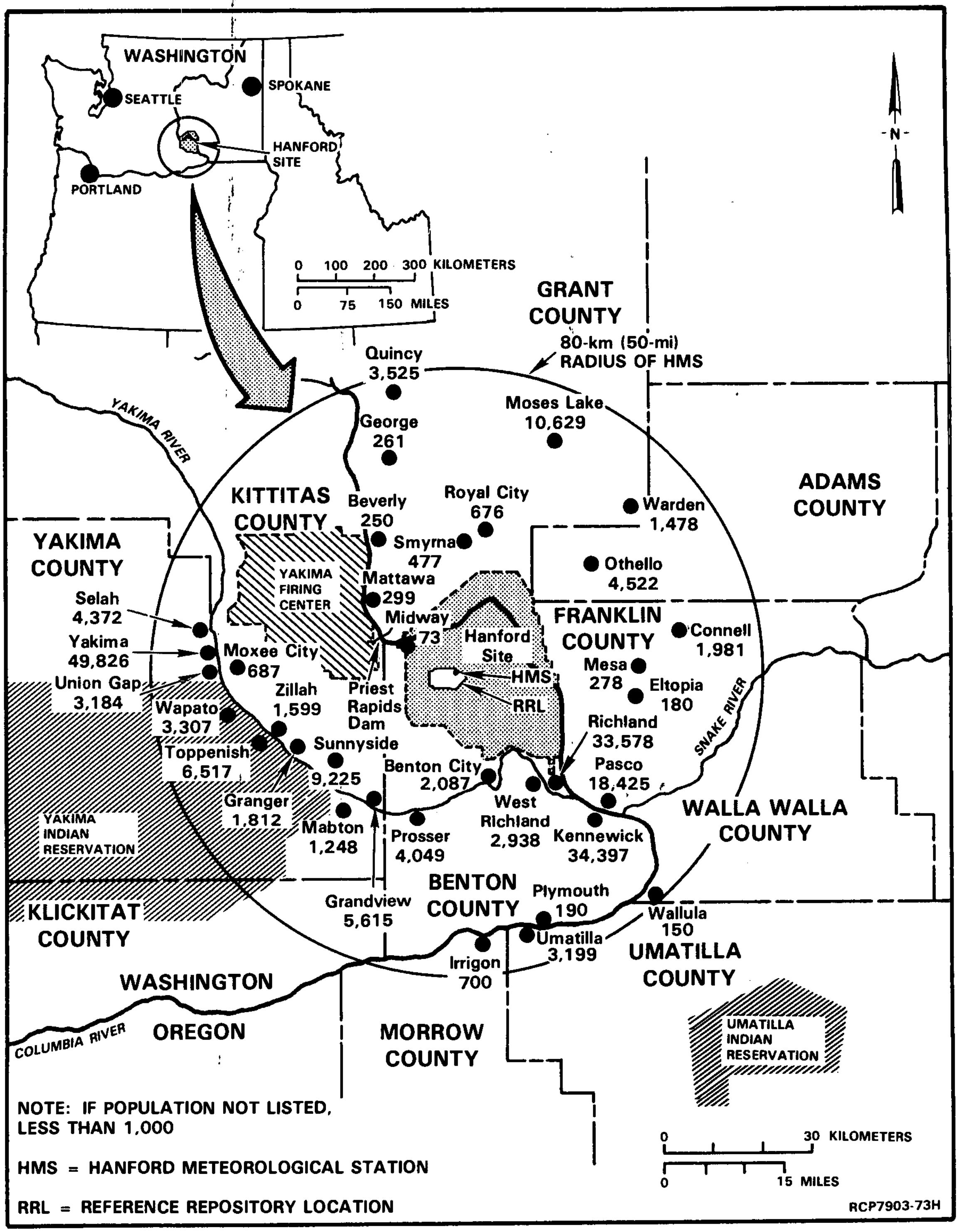

Figure 6-1. 1980 census populations for cities within an 80-kilometer (50-mile) radius of the Hanford Meteorological Station (BOC, 1981).

6.2.1.2.3 Favorable conditions

The favorable conditions for this guideline are closely related and are discussed together.

"(1) A low population density in the general region of the site.

"(2) Remoteness of site from highly populated areas."

The favorable conditions on site remoteness and low population density are present at the reference repository location. The reference repository location is remote from highly populated areas and has no permanent onsite residents.

The residential population density of the area within an 80-kilometer (50-mile) radius of the Hanford Meteorological Station, which is on the reference repository location, is 17 persons per square kilometer (43 persons per square mile). The cumulative population density within 16 kilometers (10 miles) of the Hanford Meteorological Station is 0.3 person per square kilometer (0.1 person per square mile) and 5 persons per square kilometer (14 persons per square mile) between the 16- and 32-kilometer (10- and 20-mile) radius. Most of the population is located in the outer radii. These are low population densities when compared to the mean population density of the continental United States (29 persons per square kilometer (76 persons per square mile)) or the U.S. Nuclear Regulatory Commission Regulatory Guide 4.7 (NRC, 1975) limitation of 325 persons per square kilometer (500 persons per square mile) within a 48-kilometer (30-mile) radius.

Based on U.S. Nuclear Regulatory Commission guidance (NRC, 1984, see Appendix C, Section C.7.4), the minimum allowable distance to the nearest boundary of a densely populated center is calculated to be 6.4 kilometers (4 miles). As shown in Figure 6-1, there are no highly populated areas within 16 kilometers (10 miles) of the reference repository location. As shown in Figure 3-47, there are 110 residents within the 16-kilometer (10-mile) radius (approximately 14.4 kilometers (9 miles) from the Hanford Meteorological Station).

Therefore, it is concluded that the reference repository location is remote from highly populated areas and has a low population density within an 80-kilometer (50-mile) radius of the Hanford Meteorological Station.

6.2.1.2.4 Potentially adverse conditions

The potentially adverse conditions are related and are discussed below.

"(1) High residential, seasonal, or daytime population density within the projected site boundaries.

"(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census."

These potentially adverse conditions are not present at the reference repository location. There is no permanent population or highly populated residential areas within or adjacent to the reference repository location.

There are no residential or seasonal individuals located within the 46 square kilometers (18 square miles) of the projected site boundaries of the reference repository location. The reference repository location is near the center of the Hanford Site, which is already committed to nuclear activities. There are approximately 700 daytime U.S. Department of Energy contractor employees and an additional 700 shift workers working on nuclear projects within the boundaries of the reference repository location. The daytime population density within the projected site boundary is 15 persons per square kilometer (39 persons per square mile). This is a low population density compared to the mean value for the continental United States of 29 persons per square kilometer (76 persons per square mile). Within the general vicinity of the reference repository location (i.e., within a 6.4-kilometer (4-mile) radius of the Hanford Meteorological Station), there are approximately 3,500 individuals employed in nuclear-related jobs (Table 6-2). This number of individuals is equivalent to a permanent or residential population of 885 individuals within 6.5 kilometers (4 miles) of the reference repository location. This permanent population calculation is based on the days worked, factoring in weekend and vacation time. The equivalent population density in the vicinity of the reference repository location is 7 persons per square kilometer (18 persons per square mile).

Table 6-2. Population within the general vicinity of the reference repository location

Population type	Within the boundary of the reference repository location	Within 6.4 km (4 mi) of the Hanford Meteorological Station	Within 16 km (10 mi) of the Hanford Meteorological Station
Worker population (including shift workers)	1,400	3,500	4,800
Equivalent permanent population	354	885	1,214
Equivalent population density per km^2 (per mi^2)	8 (20)	7 (18)	1.5 (4)

Extending out to the 16-kilometer (10-mile) radius, there are an additional 1,300 U.S. Department of Energy contractor employees. This equates to 329 permanent residents. The cumulative equivalent permanent population is 1,214 for a population density of 6.5 persons per square kilometer (4 persons per square mile).

At the county level, the population density for Benton County is 25 persons per square kilometer (64 persons per square mile); Franklin County is 11 persons per square kilometer (28 persons per square mile). Within an 80-kilometer (50-mile) radius of the Hanford Meteorological Station on the reference repository location, the population density is 17 persons per square kilometer (43 persons per square mile). As previously discussed (see Subsection 6.2.1.2.3), the reference repository location is remote from highly populated areas.

6.2.1.2.5 Disqualifying conditions

"A site shall be disqualified if—

"(1) Any surface facility of a repository would be located in a highly populated area; or

"(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or

"(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3A (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10 CFR Part 60, Subpart I, 'Emergency Planning Criteria.' "

The evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2). The site is not located in or adjacent to a highly populated area. There is little or no uncertainty in relation to this disqualifying condition. The reference repository is located on the Hanford Site, which has been under Federal jurisdiction since 1943. Land adjacent to the Hanford Site is privately owned, with the exception of those areas controlled by the State of Washington, county, and city governments (see Fig. 3-37). Because access to the Hanford Site is controlled by the U.S. Department of Energy, there are no highly populated areas within 16 kilometers (10 miles) of the reference repository location (see Fig. 6-1). The evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).

The city of Sunnyside, Washington (1980 population of 9,229 (BOC, 1981, p. 13)) is approximately 24 kilometers (15 miles) southwest of the reference repository location and is the closest population center. The city of Richland, Washington, with a 1980 population of 33,578 (BOC, 1981, p. 13), is approximately 35 kilometers (22 miles) southeast of the reference repository location and is the second closest population center. The cities of Kennewick, Washington (1980 population of 34,397 (BOC, 1981, p. 12)) and Pasco, Washington (1980 population of 18,425 (State of Washington, 1982, p. 3)) are located approximately 45 kilometers (28 miles) southeast of the reference repository location.

The evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2). The U.S. Department of Energy has a radiological emergency response plan and emergency procedures for the Hanford Site (DOE, 1982b, 1982d) that conform to DOE Order 5500.3A (DOE, 1981b). Furthermore, the plan and procedures agree, in general, with U.S. Nuclear Regulatory Commission radiological emergency response criteria (NRC, 1980). These plans and procedures could be expanded to cover a repository on the Hanford Site. The established plan demonstrates that the Hanford Site has the transportation system and the capability to protect the public in the event of an emergency.

In addition, an emergency response plan (WPPSS, 1983) has been approved by the U.S. Nuclear Regulatory Commission and implemented by the Washington Public Power Supply System for a commercial reactor located on the Hanford Site. This plan was prepared in conjunction with the State of Washington and Benton and Franklin Counties, and was developed to meet the intent of U.S. Nuclear Regulatory Commission radiological emergency response criteria (NRC, 1980). A coordinated training program exists among the U.S. Department of Energy, Washington Public Power Supply System, Benton and Franklin Counties, and the State of Washington to implement a unified effort to assess hazards, make decisions, and initiate action to protect public health during an emergency.

These emergency preparedness plans are continually updated to reflect changed or additional criteria developed by the U.S. Nuclear Regulatory Commission or U.S. Federal Emergency Management Agency. If the reference repository location were selected, the Hanford Site emergency response plan will be reviewed during site characterization to develop specific procedures to cover repository activities.

6.2.1.2.6 Conclusions on qualifying condition

The evidence does not support a finding that the reference repository location is not likely to meet the population density and distribution qualifying condition (Level 3). The following factors support this finding.

- The reference repository location is remote from highly populated areas. Most of the population within 80 kilometers (50 miles) is more than 32 kilometers (20 miles) away from the proposed repository site (see Subsection 6.2.1.2.3).

- There is no permanent population on the reference repository location. There are 110 residents within 16 kilometers (10 miles) of the Hanford Meteorological Station.

- Estimates of radiation doses to the public from normal operations and from accidents, including the worst-case accident, are well within the guidelines set forth in 10 CFR 20 (NRC, 1985b), 10 CFR 60 (NRC, 1985a), and 40 CFR 191, Subpart A (EPA, 1985) (see Section 6.4.1). Doses to individuals working in the vicinity of the area are monitored to ensure compliance with applicable Federal standards (Price et al., 1985).

- Existing meteorological conditions indicate that repository operations would not result in doses to the general public above allowable limits (see Subsection 6.2.1.4).

Some of the relevant data for these evaluations contain uncertainties requiring that assumptions be made, and thus result in subjective evaluations. Among the sources of uncertainty are dose calculations based on a repository design in the conceptual stage. Little or no uncertainty is associated with the census data used in evaluating this qualifying condition.

6.2.1.3 <u>Site ownership and control (Section 960.5-2-2)</u>

6.2.1.3.1 Qualifying condition

> "The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1)."

6.2.1.3.2 Evaluation process

Lands within the reference repository location have been under the jurisdiction of the Federal Government since 1943 (see Section 3.4.1). The Hanford Site is managed by the U.S. Department of Energy. Two parcels of land within the Hanford Site are leased to the State of Washington and the Washington Public Power Supply System (see Fig. 3-37). The State sub-leases a portion of its leased land to U.S. Ecology, Inc., for disposal of low-level radioactive wastes. A portion of the State of Washington-leased land is encompassed within the reference repository location, but is not expected to conflict with site-characterization activities and is not in an area where surface or subsurface areas of the repository are currently planned. Use of the leased land is limited to nuclear activities compatible with U.S. Department of Energy activities and is subject to U.S. Department of Energy approval of proposed uses. The U.S. Department of Energy retains the ability to terminate the lease for the unused portions of the leasehold if desired.

The Washington Public Power Supply System-leased land is the site for three nuclear power reactors. The State also retains fee title to a section of land for use as a proposed nonradioactive hazardous waste-disposal site. In addition, the Big Bend Alberta Company owns the mineral rights to several parcels of land within the Arid Lands Ecology Reserve.

The lands designated for the reference repository location (see Fig. 2-28) consist of acquired lands plus the following public domain:

- Township 12 North, Range 25 East of the Willamette Meridian, Section 2, part of Section 4, Section 10, Section 12, and part of Section 14.
- Township 12 North, Range 26 East of the Willamette Meridian, part of Section 4, Section 6, Section 8, and part of Section 18.
- Township 13 North, Range 26 East of the Willamette Meridian, part of Section 32.

Sections 10 and 4, Township 12 North, Range 25 East of the Willamette Meridian have been withdrawn from all forms of appropriation under the public land laws, including the mining and mineral leasing laws, and have been reserved for use by the U.S. Atomic Energy Commission in connection with its Hanford Site operations. The pertinent part of applicable Public Land Order 1273 (BLM, 1956), dated March 4, 1956, reads as follows:

> "Subject to valid existing rights, the following-described public lands in Washington are hereby withdrawn from all forms of appropriation under the public-land laws, including the mining and the mineral-leasing laws, and reserved for use of the Atomic Energy Commission in connection with its Hanford Operations."

All functions of the U.S. Atomic Energy Commission with respect to the Hanford Site and certain other locations have been transferred to the U.S. Department of Energy. As a result, said Sections 10 and 4, Township 12 North, Range 25 East of the Willamette Meridian are under the jurisdiction of the U.S. Department of Energy, which holds that land pursuant to Public Land Order 1273.

The other sections or partial sections of public domain first described above have been withdrawn and reserved for use by the U.S. Atomic Energy Commission and held by it as agent of and on behalf of the United States as provided in Public Law 88-557. That legislation also provides in pertinent part that

> ". . . the Atomic Energy Commission shall exercise all of the authorities with respect thereto as provided in the Atomic Energy Act of 1954, as amended, and the Atomic Energy Community Act of 1955, as amended: Provided, That any disposal of such lands pursuant to such Acts shall be subject to valid existing rights in third parties: Provided further, That nothing herein shall be deemed to add to, modify, or eliminate any authority of the Commission pursuant to such Acts to dispose of property."

As a result of the above-described transfer of functions from the U.S. Atomic Energy Commission to the U.S. Department of Energy, these other sections (other than Sections 10 and 4, Township 12 North, Range 25 East of the Willamette Meridian) or partial sections of public domain are also under the jurisdiction of the U.S. Department of Energy.

Most of the Hanford Site south of the Columbia River is fenced and (or) posted to prohibit access by unauthorized personnel. The State of Washington has an easement through the Hanford Site for Route 240. A portion of Route 240 crosses a corner of the reference repository location (see Fig. 3-37). This easement is fenced on both sides and is patrolled to control access to the Hanford Site (including the proposed location for repository surface facilities). Authorized access to the proposed repository surface facilities can only be gained by passing through one of several security checkpoints.

6.2.1.3.3 Favorable condition

> "Present ownership and control of land and all surface and subsurface mineral rights and water rights by the DOE."

This favorable condition is present at the reference repository location, since the Federal Government owns and the U.S. Department of Energy controls the land and all mineral and water rights. No potential impact is foreseen between State of Washington-leased land and site-characterization activities.

The Hanford Site has been under the jurisdiction of the Federal Government since 1943 with the exception of the 1977 transfer of 2.6 square kilometers (1 square mile) of limited surface rights to the State of Washington for a proposed nonradioactive hazardous waste-disposal site. This land is located 9 kilometers (5.5 miles) south of the reference repository location (see Fig. 3-37). The lands designated as the reference repository location consist of acquired land plus sections that have been withdrawn from all forms of appropriation under the public land laws (see Subsection 6.2.1.3.2). Present ownership and control of the land and all surface and subsurface mineral rights is by the Federal Government and the U.S. Department of Energy. Current and projected land use associated with U.S. Department of Energy defense facilities in the 200 West Area and State of Washington-leased land are not expected to conflict with potential site-characterization or repository activities (see Subsections 4.2.2.6 and 5.2.3.6).

6.2.1.3.4 Potentially adverse condition

"Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings."

This potentially adverse condition is not present at the reference repository location since the Federal Government owns and the U.S. Department of Energy controls the land under study.

There are no projected land-ownership conflicts. The U.S. Department of Energy controls the land within the boundaries of the reference repository location (see Subsection 6.2.1.3.2).

6.2.1.3.5 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location on the Hanford Site is not likely to meet the site ownership qualifying condition (Level 3). Supporting this finding are the following factors.

- Lands within the reference repository location have been under the jurisdiction of the Federal Government since 1943.

- Present ownership and control of the reference repository location and all surface and subsurface mineral rights are by the Federal Government and the U.S. Department of Energy.

6.2.1.4 Meteorology (Section 960.5-2-3)

6.2.1.4.1 Qualifying condition

"The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1)."

6.2.1.4.2 Evaluation process

Expected meteorological conditions during repository operations and closure can, with high certainty, be likely not to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1) of the General Siting Guidelines (DOE, 1984a). This is based on the meteorological conditions summary in Section 3.4.2, which is supported by over 40 years of data collected at the Hanford Meteorological Station. A summary of the Hanford Site meteorology is given in Stone et al. (1983).

Limiting radionuclide releases to an unrestricted area is dependent on the characteristics of the radiological source type, source concentration, and atmospheric transport parameters. Atmospheric transport (dispersion) is primarily a function of the horizontal and vertical distribution of temperature, moisture, and wind direction and velocity parameters in the atmosphere. Generally speaking, relative higher probabilities of effective transport of radionuclides (poor dispersion) will prevail when an effluent is released into a stable layer with a low capping inversion and light winds. Conversely, relative lower probabilities of effective transport of radionuclides (good dispersion) will prevail when winds are moderate to strong in neutrally or unstable stratified atmosphere with deep mixing.

A range of dispersion-dependent characteristics exists at the Hanford Site. Monthly average wind speeds are highest during the summer (14 to 16 kilometers (9 to 10 miles) per hour), supporting relatively good dispersion conditions, and are relatively lower (10 to 11 kilometers (6 to 7 miles) per hour) in the winter, supporting relatively moderate to poor dispersion conditions. The probability of inversion persistence (atmospheric stability) for more than 24 hours reaches a maximum of slightly more than 2 percent in January and February. Such information supports the conclusion that expected meteorological conditions during repository operations and closure can be likely not to lead to radionuclide releases to an unrestricted area greater than those allowable.

6.2.1.4.3 Favorable condition

"Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposure to any member of the public in the vicinity of the repository."

This favorable condition is considered to be present, since existing meteorological conditions combined with low population density and distance to highly populated areas indicate that repository operation and closure would control radiation doses to the general public within applicable limits.

Detailed atmospheric transport modeling has not been conducted for radionuclide releases at the proposed repository surface facilities. Effects of radionuclide releases on any member of the public are estimated at this time (see Section 6.4.1). The frequency of favorable dispersion conditions, as measured at the Hanford Meteorological Station, and favorable radiological monitoring and modeling results from existing Hanford Site facilities (see Subsection 3.4.2.7.5) lead to the conclusion that a number of favorable factors exist that are expected to allow repository operation to comply with the limits established by the U.S. Nuclear Regulatory Commission in 10 CFR 20 (NRC, 1985b) and by the U.S. Environmental Protection Agency in 40 CFR 191, Subpart A (EPA, 1985). Due to the low population density of the surrounding area and the distance from the proposed repository site to population centers, routine repository operations and closure activities would not be expected to result in radiation exposure to members of the general public. In the final environmental impact statement for disposal of commercially generated radioactive wastes (DOE, 1980), it was calculated that even for the most severe operational accident postulated for a generic repository (dropping a container down a repository shaft resulting in an expected release of approximately 4,000 curies of krypton-85), a 70-year whole-body radiation dose of approximately 0.04 millirem would be the maximum dose to an individual. The repository design would incorporate filtration and adsorption systems to limit gaseous and particulate radioactive emissions below the levels allowed by the U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency (see Section 5.1.2).

The Plutonium and Uranium Recovery through Extraction (PUREX) plant at the Hanford Site resumed operation in November 1983. The major emission from PUREX in 1984 was 400,000 curies of krypton-85 (Price et al., 1985). Even though the curie quantity of this nuclide was large, it was a minor contributor to the radiation dose. The average concentration of krypton-85 at the perimeter monitoring stations was 75 picocuries per cubic meter, which produced a whole-body dose of 0.001 millirem and a skin dose of 0.1 millirem. Additionally, monitoring of Hanford Site facilities (Price et al., 1985) indicates that the dose to an individual in the vicinity of the Hanford Site is approximately 2 millirems to the whole body.

6.2.1.4.4 Potentially adverse condition

"(1) Prevailing meteorological conditions such that radioactive emissions from repository operation or closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region."

This potentially adverse condition for the meteorology guideline is considered present at the reference repository location. This condition is interpreted to be concerned primarily with wind direction and not preferential transport. The site is remote from highly populated areas and emissions are expected to be effectively dispersed.

As previously discussed in Subsection 3.4.3.1, the prevailing wind direction observed at the Hanford Meteorological Station is from the northwest. Winds from this direction occur 16 percent of the time. Several localities (e.g., Richland, Pasco, and Kennewick, Washington) lie within the downwind sector from the Hanford Meteorological Station. Preferential transport toward these localities is conservatively considered present, although the prevailing wind direction of these localities is from the southwest. Dispersion characteristics, wind channeling, and distance from the repository would reduce exposure to the public at these localities if releases were to occur (see Subsection 6.2.1.4.3).

6.2.1.4.5 Potentially adverse condition

"(2) History of extreme weather phenomena--such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms—that could significantly affect repository operation or closure."

This potentially adverse condition is not present at the reference repository location. Such extreme weather conditions do not occur or rarely occur at the Hanford Site.

Extreme weather phenomena rarely occur in the Hanford Site region. Hurricanes do not occur on the Hanford Site. Tornadoes and funnel clouds, as discussed in Subsection 3.4.3.1, are a rare occurrence. From 1916 to 1983, 22 tornadoes were sighted within a 160-kilometer (100-mile) radius of the Hanford Meteorological Station. The recurrence interval at any point within this radius is estimated to be one tornado per 146,000 years (Stone et al., 1983). Other conditions with high winds are thunderstorms and summertime afternoon drainage winds. Severe winter storms are seldom experienced in the Hanford Site region.

Meteorological phenomena that will be considered for design and operating bases of the repository have been identified (DOE, 1982e) and include the following:

- The probability and expected characteristics of a tornado occurring in the Hanford Site support a Class III designation for the region for design purposes.

- The structures at the reference repository location will be designed to withstand a basic wind velocity of 130 kilometers (80 miles) per hour, based on observed and recorded information from the Hanford Meteorological Station.

- The American National Standards Institute (ANSI, 1982) provides weights of snow packs for the Hanford Site region. The 100-year ground-level snow pack is 98 kilograms per square meter (20 pounds per square foot).

- The number of thunderstorms observed in the Hanford Site area has ranged from 3 to 23 per year, averaging 11 per year. Lightning strike frequency for a 125-meter (410-foot) structure can be estimated at one every 4.44 years (ERDA, 1975) for the Hanford Site area.

- The worst-case duststorm, or the storm that had the largest calculated time-integrated dust loading, was observed by the Hanford Meteorological Station to have a dust loading of 160 milligrams per hour per cubic meter, lasting 18 hours, for an average dust loading of 8.9 milligrams per cubic meter. The highest average loading for any 1-hour period is 100 milligrams per cubic meter.

6.2.1.4.6 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Factors supporting this finding include the following:

- Existing meteorological conditions, data for which have been collected on the reference repository location for over 40 years, combined with low population density and distance to highly populated areas indicate that any radiological emissions would be effectively dispersed before they reach highly populated areas.

- Estimated repository emissions, under routine operating conditions, are not expected to result in radiation releases above allowable limits to unrestricted areas.

- Radiological emissions from existing Hanford Site facilities have resulted in minimal doses to individuals in the vicinity of Richland, Washington.

There is little uncertainty associated with the meteorological data and supporting analyses.

6.2.1.5 Offsite installations and operations (Section 960.5-2-4)

6.2.1.5.1 Qualifying condition

"The site shall be located such that present and projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in Section 960.5-1(a)(1)."

6.2.1.5.2 Evaluation process

Radiological and nonradiological effects of offsite installations and operations on the reference repository site will be evaluated. A discussion of radiological background and the impact of Hanford Site defense waste activities is provided in Subsection 3.4.2.7. Figure 3-37 depicts current land use on the Hanford Site.

Impacts of facilities off the reference repository location were considered during site-identification studies (WCC, 1981). Screening guidelines for the reference repository location excluded, to the extent possible, potential repository sites that were subject to the effects of manmade hazards (see Section 2.2). These guidelines addressed potentially adverse effects from aircraft impact, hazardous facilities, transportation systems, induced seismicity, subsurface mineral exploration and extraction, and national defense and security facilities that were interpreted as attractive military targets.

Manmade hazards identified in the vicinity of the reference repository location included high-altitude jet routes, nearby radioactive waste-management and -disposal facilities, and national defense and security aspects of nearby Hanford Site operations. The high-altitude commercial jet route crossing the site presents a negligible risk to repository facilities. Low-probability accidents at nearby facilities in the 200 Areas could result in temporary disruption of repository construction and (or) operation.

Radioactive emissions to unrestricted areas from nuclear waste repositories are governed by 10 CFR 20 (NRC, 1985b) (as referenced by 10 CFR 60 (NRC, 1985a) and 40 CFR 191 (EPA, 1985)). In 10 CFR 20, the U.S. Nuclear Regulatory Commission requires that radioactive effluents meet specified concentration guides and that the maximum whole-body dose to an individual in unrestricted areas be limited to 500 millirems per year. In 40 CFR 191, Subpart A requires that repository operations in addition to other commercial nuclear fuel cycle facilities covered by 40 CFR 190 (EPA, 1977) do not result in whole-body doses to members of the public greater than 25 millirems per year. Nuclear facilities operated by the U.S. Department of Energy at the Hanford Site are subject to standards set forth in DOE Order 5480.1A (DOE, 1981a), which is effectively identical to 10 CFR 20, and are considered separately under 40 CFR 61 (EPA, 1973, as amended).

Radioactive emissions and associated dose rates to the public from repository operations at the Hanford Site have been estimated (Section 6.4.1). The projected dose is sensitive to assumptions concerning storage and handling capacity of the facility, age of the waste, and whether or not the facility is designed to accept, store, disassemble, and package spent fuel. The 1982 conceptual design (RKE/PB, 1983) for the nuclear waste repository was based on the receiving and handling of prepackaged spent fuel and high-level nuclear waste (see Section 5.1.2). Under these conditions radioactive emissions would occur if externally contaminated or leaking containers were received, or if intact containers were damaged at the repository. The disassembly, storage, and packaging of spent fuel would have a potential for gaseous radioactive emissions. Based on estimated routine radioactive gaseous emissions from spent fuel disassembly and packaging operations, the maximum annual dose to an individual living 24 kilometers (16 miles) from the point of release would be approximately 0.001 millirem (Subsection 6.4.1.4).

Licensed commercial nuclear facilities located within the Hanford Site boundaries include the Washington Public Power Supply System reactor site and a commercial low-level radioactive waste-burial site (see Fig. 3-37). The Exxon Nuclear Company, Inc., fuel fabrication facility is located adjacent to the southern boundary of the Hanford Site.

The Hanford Site includes four major U.S. Department of Energy operating areas, the 100, 200, 300, and 400 Areas as shown in Figure 3-37. The State of Washington leases a parcel of land south of the 200 Areas and subleases a portion to U.S. Ecology, Inc., for the management of commercial low-level radioactive wastes. Operation of the U.S. Ecology, Inc., facility is permitted and regulated by the State of Washington and the U.S. Nuclear Regulatory Commission. The Washington Public Power Supply System leases a parcel of land that is the site for three nuclear power reactors: 1,100-megawatt nuclear electric-generating plant is in operation, construction is deferred on another, and a third project under construction has been terminated. The operating plant is licensed and regulated by the U.S. Nuclear Regulatory Commission. The 100 Areas contained nine plutonium production reactors, eight of which were shut down between 1965 and 1971. The N Reactor is the only remaining operating plutonium-production reactor on the Hanford Site. Steam generated by the reactor is purchased by the Washington Public Power Supply System to operate the Hanford Generating Project. The Hanford Generating Project produces 860 megawatts of electricity for distribution in the northwest. The N Reactor is the major contributor to the radiological dose from Hanford Site operations, primarily through the liquid discharges to the Columbia River (Price et at., 1985).

The PUREX plant and associated facilities in the 200 Areas chemically dissolve the irradiated fuel from N Reactor, and the plutonium and uranium are removed and processed into finished materials. Wastes from the chemical processing are stored and managed in the 200 Areas. The PUREX plant resumed operation in November 1983. The major emission from PUREX in 1984 was 400,000 curies of krypton-85. Even though the curie quantity of this nuclide was large, it was a minor contributor to the radiation dose. The average concentration of krypton-85 at the perimeter monitoring stations was 75 picocuries per cubic meter, which produced a calculated whole-body dose of 0.001 millirem and a skin dose of 0.1 millirem (Price et al., 1985).

The 300 Area contains reactor fuel manufacturing facilities and research and development laboratories. Descriptions of these facilities have been published (ERDA, 1975; DOE, 1982a; UNC, 1979) and the total radiological emissions from each of the operating areas have been published in the annual environmental-monitoring report during the last 25 years (Price et al., 1985).

Operations in the 400 Areas are in support of the development of liquid metal fast breeder reactor technology. The major facility is the Fast Flux Test Facility, which is a 400-megawatt sodium-cooled reactor for testing breeder fuels, materials, and components.

Radiation dose equivalents, resulting from emissions from Hanford Site facilities, are calculated by the Pacific Northwest Laboratory for the U.S. Department of Energy on an annual basis as part of an environmental surveillance program (Price et al., 1985). Measurements are made of external radiation from air, Columbia River water, ground water, foodstuffs, wildlife, and soils and vegetation.

Radiological data from the Hanford Site are used to calculate the dose to a hypothetical individual whose location and characteristics are chosen to maximize the combined doses from all realistically available exposure pathways. The maximum dose to an individual is believed to represent an appropriate means of demonstrating compliance with regulatory standards. Based on analyses of 1984 environmental surveillance data Price et al. (1985, p. 57) stated that:

> "An assessment of potential radiological impact from Hanford operations during 1984 indicated that radiation doses to the public were well below all applicable regulatory limits and were substantially less than doses potentially received from common sources of radiation. The calculated fifty-year whole body cumulative dose received by a hypothetical maximally exposed

"individual was about 2 mrem. The calculated fifty-year whole body cumulative dose to the surrounding population was about 5 man-rem. The average per capita whole body dose was estimated at 0.01 mrem per person. These doses can be compared to the approximate 100 mrem and 34,000 man-rem doses received annually by an average individual and the surrounding population, respectively, as a result of naturally occurring radiations in our environment. The assessment of potential radiation doses due to residual radionuclides from past Hanford operations also identified no significant impacts on the public. Measured and calculated doses were well below applicable radiation dose standards."

The calculated annual maximum individual dose commitment (whole body) from 1984 Hanford Site operations amounted to 0.01 millirem. This includes calculated emissions from all defense nuclear facilities on the Hanford Site. Operation of the Washington Public Power Supply System nuclear power reactors (see Fig. 3-37) would add to the calculated dose from 1984 defense operations. The projected maximum annual dose to an individual (whole body) from the operation of three Washington Public Power Supply System reactors is approximately 2.7 millirems (WPPSS, 1977a). Therefore, the total maximum annual dose to an individual from all existing and planned commercial and defense nuclear facilities is approximately 2.8 millirems. When combined with the estimated dose from preclosure repository operations of 0.001 millirem (Section 6.4.1), the total maximum annual dose to an individual residing near the Hanford Site is approximately 2.8 millirems.

The Yakima Firing Center is used primarily as a training area for large-scale maneuvers, particularly those involving tracked vehicles (tanks and armored personnel carriers) and for training in use of large, long-range weapons. The use of the Yakima Firing Center is necessary to enhance the ability and readiness of the primary headquarters, 9th Infantry Division, Fort Lewis, and reserve components (U.S. Army Reserve, National Guard) in accomplishment of their military mission.

In an environmental impact statement issued by the U.S. Department of the Army in 1977 (DOA, 1979, pp. 67-109), no current or proposed activity on the Yakima Firing Center was identified that would significantly affect nuclear-related operations on the Hanford Site. These included assessments of land use, environmental or socioeconomic impacts resulting from any current or proposed activity on the Yakima Firing Center (see Subsection 3.1.4.2).

The U.S. Air Force is evaluating potential locations for deployment of small intercontinental ballistic missiles, in response to the recommendations of the President's Commission on Strategic Forces. Three modes of deployment are being considered: Hard silos, hard mobile launchers, and hard mobile launchers in a confined area at existing minuteman complexes. The U.S. Air Force is examining 51 sites in 14 states: 22 of these sites are being considered for hard mobile launchers with random movement, 6 for mobile launchers in a confined area, and some of these sites plus the remaining sites are being considered for hard silo deployment. The Hanford Site is one of the sites under consideration for hard mobile launcher deployment. The U.S. Air Force is evaluating land available at the Hanford Site for deployment of hard mobile launchers that will not conflict with existing facilities or approved missions. Potential conflicts have been identified by the U.S. Department of Energy and include a mission conflict with nuclear materials production, a mission conflict with a site for a future commercial nuclear reactor, severe administrative conflicts on safeguards and security and environmental safety and health, and telecommunications and coordination of non-U.S. Department of Energy activities. Additional information on the U.S. Air Force site-evaluation process is expected in 1986. At present, the limited amount of information available on which areas will be selected, the sites within those areas, and the extent of the land required to support deployment make it impossible to evaluate effects at this time.

Plans for future activities at the Hanford Site include a process facility modification project and waste tank disposal operations. These planned activities are not expected to conflict with potential repository activities.

Radioactive emissions and associated estimates of dose rates to the public from repository facilities that might be located at the Hanford Site are discussed in Subsections 6.2.2.1 and 6.4.1.4.

6.2.1.5.3 Favorable condition

"Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A."

This favorable condition is not present at the reference repository location since there are other nuclear facilities at the Hanford Site that are subject to the requirements of 40 CFR 191, Subpart A (EPA, 1985).

Radioactive emissions subject to consideration under 40 CFR 191, Subpart A, include the Washington Public Power Supply System nuclear reactors and the Exxon Nuclear Company, Inc., fuel fabrication facility. Defense activities on the Hanford Site are considered separately under 40 CFR 191, Subpart A (EPA, 1985).

6.2.1.5.4 Potentially adverse condition

"(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure."

This potentially adverse condition is present at the reference repository location. Design basis accidents at nearby facilities could result in temporary disruption of repository operations.

Low-probability accidents at nearby facilities in the 200 Areas could result in temporary disruption of repository operations. The actual and projected releases from other nuclear installations in the vicinity of the proposed repository site are substantially less than the standards of 40 CFR 190 (EPA, 1977), and 40 CFR 191, Subpart A (EPA, 1985).

Potentially hazardous installations and operations on the Hanford Site vicinity were identified during site-screening studies (WCC, 1981). To the extent possible, those potential repository sites that were subject to effects of manmade hazards were eliminated from consideration (see Section 2.2). The residual risk from manmade hazards was judged to be acceptable.

6.2.1.5.5 Potentially adverse condition

"(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards."

This potentially adverse condition is not present at the reference repository location. Actual and projected radioactive releases are substantially less than federally established exposure standards.

Installations off the repository site subject to 40 CFR 190 (EPA, 1977) and 40 CFR 191, Subpart A (EPA, 1985) include commercial nuclear fuel cycle facilities planned or in operation at the Hanford Site. In addition, the U.S. Department of Energy-operated nuclear facilities are subject to DOE Order 5480.1A (DOE, 1981a). During routine operations, the calculated maximum annual dose to an individual due to current and projected commercial facilities and the U.S. Department of Energy nuclear facilities (including estimated repository emissions) is approximately 2.8 millirems (see Subsection 6.2.1.5.2). This value is substantially less than the annual 25-millirem exposure limit set by the U.S. Environmental Protection Agency (EPA, 1985).

6.2.1.5.6 Disqualifying condition

"A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with repository siting, construction, operation, closure, or decommissioning."

The evidence does not support a finding that the reference repository location is disqualified (Level 1). The proximity of the reference repository location to nuclear defense facilities is not expected to pose irreconcilable conflicts. From a siting standpoint, many of the attributes of the Hanford Site favorable for atomic energy defense facilities, particularly those associated with its comparative remoteness, also support its potential suitability as a repository site.

During construction, operation, closure, or decommissioning of a repository, the principal potential hazard from nearby facilities would result from a low-probability accidental release of radioactive particulates. Such an event could cause temporary suspension of repository operations under adverse meteorological conditions, but would not permanently impair construction work or repository performance. Nearby defense nuclear facilities are potential terrorist targets; therefore, a security force is maintained to protect these facilities. Thus, the reference repository location would benefit from security measures already in place at the Hanford Site.

Low-probability design basis accidents at nearby nuclear facilities could result in temporary disruption of repository construction, operation, closure, or decommissioning.

The actual and projected releases from these nearby facilities are substantially less than the standards of 40 CFR 190 (EPA, 1977) and 40 CFR 191, Subpart A (EPA, 1985).

6.2.1.5.7 Conclusions on qualifying condition

The evidence does not support a finding that the site is not likely to meet the offsite installations and operations qualifying condition (Level 3). Factors that support this conclusion are summarized below.

- A screening process that addressed and avoided potentially adverse effects from nearby facilities and manmade hazards was used to select the reference repository location.
- Actual and projected radioactive releases from other nuclear facilities are substantially less than federally established exposure standards.
- The probability of design basis accidents at nearby nuclear facilities that could result in temporary disruption of repository construction, operation, closure, or decommissioning is considered low.

There is little uncertainty related to these supporting factors.

6.2.1.6 Environmental quality (Section 960.5-2-5)

6.2.1.6.1 Qualifying condition

"The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in Section 960.5-1(a)(2) can be met."

6.2.1.6.2 Evaluation process

The reference repository location is situated on the U.S. Department of Energy-controlled 1,500-square-kilometer (570-square-mile) Hanford Site, which has been dedicated to nuclear activities since 1943. Environmental analyses conducted for the U.S. Department of Energy nuclear activities indicate that compliance with environmental laws and regulatory requirements would not be a problem if a repository were located at the Hanford Site (ERDA, 1975; DOE, 1982a, 1983a). The Hanford Site is not located within the boundaries of a significant nationally protected natural resource. Construction and operation of a repository would not be inconsistent with existing land-use plans, and impacts associated with these activities would be relatively minor. No adverse environmental impacts, which cannot be mitigated, have been identified (see Section 5.2).

6.2.1.6.3 Favorable conditions

"(1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon."

This favorable condition is considered present, since the reference repository location is expected to meet all procedural and substantive environmental requirements applicable to the site.

The U.S. Department of Energy (DOE, 1984b) has established a policy to assure incorporation of environmental protection goals in the formulation and implementation of a repository system. Given this policy and the long lead time to repository construction activities, the U.S. Department of Energy does not expect an inability to meet procedural and substantive environmental requirements applicable to the site and the proposed activities. A list of major Federal laws and other legal requirements that were reviewed for applicability in making this determination for a repository at the reference repository location is set forth in Table 6-3.

The U.S. Department of Energy intends to comply with State and local environmental regulations consistent with its responsibilities under the Nuclear Waste Policy Act of 1982. The U.S. Department of Energy intends to consult with State and local officials concerning the scope and applicability of the following regulations and to identify other regulations as appropriate if the reference repository location were recommended for site characterization.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 1 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
American Antiquities Act (16 USC 433)	The American Antiquities Act protects historic and prehistoric ruins, monuments, objects of antiquity located on lands owned or controlled by the Federal Government.	If historic or prehistoric ruins or objects of antiquity are found on DOE-owned land, DOE must determine if the project will adversely impact resources.	DOE has conducted surveys of the reference repository location and found nothing significant (see Sections 4.2 and 5.2). During repository construction, DOE would perform assessments of potential impact on any resources identified and take appropriate measures to avoid or remove such resources.	DOE projects ability to comply, because DOE is committed to avoid or to remove any resources discovered in accordance with the Act if the resource may be affected during characterization or construction activities.
American Indian Religious Freedom Act (42 USC 1996)	The American Indian Religious Freedom Act protects and preserves Native American religious and practice.	DOE must determine if the reference repository location is in an area related to Indian religious sites or is a sacred site of any Native American group. If the site is in such an area, DOE must consult Native American leaders to determine if the project would infringe on religious practices. If infringement is possible, DOE must consider alternatives; if no feasible alternative is available, the project must be reviewed by the Office of Intergovernmental Affairs and approved by the Secretary of Energy.	DOE has determined that no such sites have been identified on the reference repository location. For site-characterization activities off the reference repository location, DOE will determine if impacts to potential or existing religious sites will be significant. DOE will consult with the appropriate groups to develop mitigative strategies.	DOE projects compliance with this Act, because no religious or sacred sites exist on the reference repository location.
Archaeological Resource Preservation Act (16 USC 470)	The Archaeological Resource Preservation Act protects archaeological resources located on United States public lands or Indian lands.	DOE must determine if archaeological resources, which are present on land owned by DOE, may be damaged during activities, and hence must be excavated or removed. If so, the Secretary of Energy must give permission to perform the excavation or removal.	DOE has conducted preliminary archaeological field studies on the reference repository location in 1981 and 1982 (see Section 3.4.6) and no archaeological resources were identified.	DOE projects compliance with the Act, because no listed or eligible archaeological resources are known to exist on the reference repository location. Potential impacts off the reference repository location will be mitigated (see Section 3.4.6).

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 2 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Bald and Golden Eagle Protection Act (16 USC 668-668d)	The Bald and Golden Eagle Protection Act prohibits possessing, killing, transporting, disturbing, et cetera of bald and golden eagles, their nests, or eggs.	DOE activities must avoid negative impacts (including indirect effects) to bald and golden eagles, their nests, and eggs. If a golden eagle nest is found and must be moved, the Secretary of the Interior may permit relocation of nests if they interfere with resource development or recovery plans.	DOE has performed a census for eagles on the Hanford Site and determined that they do not use the reference repository location for critical habitat. They do occur along the Columbia River during short periods (see Subsection 3.4.2.5).	DOE projects compliance with the requirements of this Act, because eagles are not known to nest on the reference repository location and DOE has flexibility regarding the timing and placement of borehole-drilling activities. DOE will implement appropriate mitigation measures, after consultation with the U.S. Fish and Wildlife Service and the State wildlife agency, if they become necessary.
Clean Air Act (Prevention of Significant Deterioration and Other Air Quality Approvals, 42 USC 7401)	The Clean Air Act is a statute for the prevention and control of air pollution from stationary and mobile sources.	DOE must determine if planned activities are defined as a major source. DOE must comply with State and local air-quality implementation plans, estimate emissions, compare emissions with major source definition, and perform dispersion modeling analysis to determine impacts.	Site-characterization activities on the reference repository location have to be analyzed and would not be considered a major source (see Subsection 4.2.1.3.2). Repository activities were also analyzed and are not expected to be a major source (see Subsection 5.2.1.3.2). Activities will comply with applicable regulations issued by the State of Washington and the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority.	DOE projects ability to comply with applicable State and local air-quality regulations. Fugitive dust from construction activities poses the greatest impact (see Subsection 5.2.1.3.2) and will be controlled by wet suppression methods.
Clean Water Act of 1972 (Federal Water Pollution Control Act, 33 USC 1251)	The Clean Water Act is a statute to clean up the nation's waters, provide for water pollution control, research and development, and Federal grants to municipalities.	DOE must determine if a national pollutant discharge elimination system permit (Section 402) is required for discharges to surface waters. DOE must also determine if a stream diversion and (or) channelization permit (Section 402) is required.	Site-characterization and repository activities would not require discharges to surface waters or stream diversion.	DOE projects compliance, because (1) no perennial surface waters exist on the reference repository location and (2) no modification to Cold Creek streambed (ephemeral) is envisioned.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 3 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Coastal Barrier Resources Act (16 USC 3501-3510)	The Coastal Barrier Resources Act prohibits new Federal expenditures for construction of projects within the Coastal Barrier Resources system, which consists of undeveloped coastal land along the Atlantic and Gulf Coasts and adjacent wetlands and inlets.	DOE must determine if the reference repository location or related activities are within the Coastal Barrier Resources System. If so, site and (or) activities must be abandoned. DOE should confirm with the U.S. Fish and Wildlife Service that no project activities are located in a coastal barrier.	The requirements of this Act have been analyzed against proposed project activities. No activity related to a repository at Hanford is proposed in areas covered by this Act.	This Act is not applicable to the reference repository location, because no activities are proposed within coastal barriers.
Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (42 USC 9601-9657)	The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 imposes notification requirements and liability for unpermitted releases of hazardous substances, and establishes a fund for remedial use in case of release of hazardous substances.	The U.S. Environmental Protection Agency must be notified in the event of a reportable release of a designated hazardous material.	DOE projects ability to comply, because small quantities of generated hazardous wastes will be stored in drums and then disposed of offsite at licensed facilities. DOE will comply with all notification requirements.	Hazardous waste releases are unlikely. DOE will comply with all requirements in the event of an accidental release.
U.S. Department of Transportation Acts (49 USC 303 and 23 USC 136)	The U.S. Department of Transportation Acts preserve the natural beauty of the countryside and public park and recreation lands, wildlife and waterfowl refuges, and historic sites.	The Secretary of Transportation may only approve a transportation project requiring the use of publicly owned land containing a public park, recreation area, or wildlife and waterfowl refuge of significance, or the use of land containing a historic site of significance, if there is a prudent and feasible alternative, and if mitigation planning is included.	DOE does not expect to require transportation projects using public parks, recreation areas, wildlife and waterfowl refuges, or land containing significant historic sites.	DOE projects ability to comply, because it will not use public parks, recreation areas, wildlife and waterfowl areas, or land containing significant historic sites.
Endangered Species Act (16 USC 1531)	The Endangered Species Act establishes a Federal policy to conserve endangered or threatened species of fish, wildlife, and plants.	DOE must determine if any listed or proposed endangered or threatened species or their habitat will be affected by project activities. If a listed species or habitat may be affected by the project, DOE must provide a written request for consultation to the Regional Director, U.S. Fish and Wildlife Service and follow the U.S. Fish and Wildlife Service procedures.	DOE has performed a biological assessment on the reference repository location and determined that no threatened or endangered species use that area for critical habitat (see Section 3.4.2.5). For site-characterization activities off the reference repository location, DOE will perform biological assessments and consult with the U.S. Fish and Wildlife Service if critical habitat is identified.	DOE projects ability to comply with this Act, because no threatened or endangered species use the reference repository location as critical habitat. For site-characterization activities off the reference repository location, DOE will perform biological assessments and consult with the U.S. Fish and Wildlife Service as necessary.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 4 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Farmland Protection Policy Act (7 USC 4201-4209 (7 CFR 658))	The Farmland Protection Policy Act seeks to minimize the extent to which Federal programs contribute to the unnecessary and irreversible conversion of farmland to nonagricultural uses.	For covered activities, Federal agencies must complete and submit Soil Conservation Service Form AD-1006. If the Soil Conservation Service determines that prime farmland exists, the agency must complete a site assessment using criteria set forth in 7 CFR 658 or State criteria where they exist. The agency must also consider alternative and (or) mitigating measures to protect the prime farmland, and assure to the extent practicable project compatibility with State and local programs and policies.	DOE has determined that the Act does not apply, since the lands at the reference repository location have already been set aside and reserved for use by the DOE in connection with nuclear-related activities.	DOE projects ability to comply, because there are no lands subject to these requirements at the reference repository location.
Federal Land Policy and Management Act of 1976 (43 USC 1701-1782 (43 CFR 2300))	The Federal Land Policy and Management Act of 1976 and regulations authorize and establish procedures for Federal departments and agencies to use, occupy, and develop public lands administered by the U.S. Department of the Interior through the Bureau of Land Management. These mechanisms are rights-of-way, withdrawals, and cooperative agreements.	If site characterization occurs on U.S. Department of the Interior Bureau of Land Management-managed lands, the Secretary of Energy must negotiate and execute a cooperative agreement with the Secretary of the Interior or his designee. DOE must also follow withdrawal procedures to protect the land. These procedures include: Pre-application consultation with the Bureau of Land Management, submission of application, preparation of resource management plan and implementation plan. The Secretary of the Interior can authorize withdrawals up to 20 years. Congressional approval is required for withdrawals of 2,000 hectares (5,000 acres) or more. In conducting the withdrawal activities, DOE must comply with its internal procedural requirements set forth in DOE Real Estate (Real Property) Management Order (DOE Order 4300.1A). If the repository site were to be located on U.S. Department of the Interior Bureau of Land Management-managed lands, an Act of Congress will be required for permanent withdrawal and the Federal Land Policy and Management Act of 1976 will not be applicable.	DOE has determined that all site-characterization and repository activities will occur on DOE-controlled land.	DOE projects ability to comply, because all site-characterization and repository activities will occur on DOE-controlled land.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 5 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Fish and Wildlife Coordination Act (16 USC 661-666)	The Fish and Wildlife Coordination Act mandates that wildlife conservation receive equal consideration with proposed alternative uses affecting bodies of water (or water development associated with other projects).	The Act applies only if (1) the project involves modification, control, or impoundment of a body of water, (2) surface area must be 4 hectares (10 acres) or more for impoundments, and (3) activities must be on non-Federal lands or on Federal land not under the jurisdiction of the DOE. If these conditions are present, DOE must consult with State and Federal wildlife agencies to determine measures that would prevent, mitigate, or compensate for losses of wildlife resources due to project activities. DOE must fully consider reports and recommendations from wildlife agencies, including the U.S. Department of the Interior and State agencies, and include measures that prevent, mitigate, or compensate for losses of wildlife resources in the project plan.	Site-characterization activities will not contain or modify any surface waters and all activities will be on DOE-controlled land.	DOE projects compliance with this Act, because site-characterization activities will not contain or modify any surface waters and all activities will be on DOE-controlled land.
Flood Plain/Wetlands Executive Orders (E.O. 11988 and 11990) (10 CFR 1022))	Flood Plain/Wetlands Executive Orders require Federal agencies to implement regulations that will protect wetlands and minimize adverse effects from development in flood plains.	DOE must determine if wetlands or flood plains occur at repository site or support facilities. DOE must publish notice in the Federal Register, notify Federal, State, and local agencies of proposed action, prepare an assessment of proposed action (flood plain/wetlands assessment) that includes alternative measures to minimize impacts if the project proceeds in the flood plain and (or) wetlands, and publish a statement of findings. DOE actions in flood plains must be designed to minimize harm to flood plains. Construction in a flood plain must be in accordance with Federal Insurance Administration regulations. DOE should avoid construction in a wetland unless there is no practical alternative.	DOE has determined that it is not within a 100-year flood plain. Based on a survey of the reference repository location, no wetlands have been identified.	DOE projects ability to comply with the requirements. Wetland requirements will not apply, pending confirmation from the U.S. Fish and Wildlife Service that no wetlands exist on the site or on the access routes.
Hazardous Materials Transportation Act (49 USC 1801-1812 (49 CFR 171-178))	The Hazardous Materials Transportation Act gives additional regulatory and enforcement authorities to the Secretary of Transportation to protect the nation from the risks of transporting hazardous materials.	Regulations define packaging, labeling, handling, documenting, and transporting requirements for hazardous materials, including notification procedures in the event of a spill.	DOE will comply with all regulations of the Act for transportation of any hazardous waste during site characterization and for transportation of high-level nuclear wastes during repository operation.	DOE projects ability to comply, because it will follow U.S. Department of Transportation regulations regarding the transportation of hazardous and radioactive materials.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 6 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Historic Sites, Buildings, and Antiquities Act (16 USC 461-469), Preservation of Historical Archaeological Data Threatened by Dam Construction or Alteration of Terrain (16 USC 469-469c), National Historic Preservation Act of 1966 as Amended (16 USC 470-470w-6 (36 CFR 800; Executive Order 11593))	These Acts protect properties of historical architectural significance at Federal, State, and local levels from Federal actions affecting properties included in or eligible for inclusion in the National Register of Historic Places.	DOE must request information from State historic preservation officer and study existing literature to determine whether or not a potential repository site contains any structure or object that is in the National Register or eligible for inclusion in the National Register. If resources are known to be in the same area, or if requested by the State historic preservation officer, DOE should survey the site to identify resources.	DOE has consulted with the State of Washington historic preservation officer as to which of the identified archaeological sites would be eligible for listing in the National Register. Should the reference repository location be selected for characterization, DOE will consult with the State of Washington historic preservation officer regarding the need for additional archaeological studies and eligibility of any resources identified.	DOE projects ability to comply, because it is proceeding with appropriate procedural steps mandated by the Acts. Based on consultations with the State of Washington historic preservation officer and the Advisory Council on Historic Preservation, DOE will continue archaeological surveys, determinations of eligibility, and mitigation plans.
Marine Protection Research and Sanctuaries Act of 1972 (33 USC 1401-1444 (40 CFR 220-228))	The Marine Protection Research and Sanctuaries Act of 1972 regulates the dumping into ocean waters of all types of materials.	If DOE decides to dispose of materials in ocean water, a permit is required.	DOE is not considering ocean disposal of materials.	This Act is not applicable, because no ocean disposal is planned.
Materials Act of 1979 (30 USC 601-604 (43 CFR 3620))	The Materials Act of 1979 was intended to remove common types of sand, gravel, and stone from coverage of mining laws.	A free-use permit is required from the Bureau of Land Management if DOE plans to take sand, gravel, stone, or other common materials from Bureau of Land Management land.	DOE has determined that no Bureau of Land Management land is present in the project area.	This Act is not applicable, because no Bureau of Land Management land is present in the project area.
Migratory Bird Treaty Act (16 USC 703-711 (50 CFR 10.13))	The Migratory Bird Treaty Act prohibits killing, capturing, transporting, et cetera of protected migratory birds, their nests, and eggs.	DOE activities must avoid harm (including indirect effects) to migratory birds, their nests, and eggs.	If migratory birds, their nests, and eggs are found on or near a potential site or area of characterization activity, DOE will contact the U.S. Department of the Interior to develop mitigative measures.	DOE projects ability to comply with this Act, because no protected species use the reference repository location as critical habitat. DOE will implement appropriate mitigation measures, after consultation with the U.S. Fish and Wildlife Service and the State wildlife agency, if they become necessary.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 7 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
National Environmental Policy Act of 1969 (NEPA) (42 USC 4321-4361 (40 CFR 1500)) (as directed by the Nuclear Waste Policy Act of 1982 (the Act), 42 USC 10101-10442)	The National Environmental Policy Act of 1969 establishes a national policy that will encourage productive and enjoyable harmony between people and their environment and to promote efforts to eliminate damage to the environment.	The NEPA requires Federal agencies to assess the environmental impacts of major Federal actions significantly affecting the quality of the human environment. The Act establishes that site-characterization activities are preliminary actions that do not require an environmental impact statement. Statutory environmental assessments are required for site nomination. An environmental impact statement is required for repository site recommendation. The Act provides that certain standard environmental impact statement content requirements need not be included.	This document is the statutory environmental assessment under this Act. DOE plans to prepare an environmental impact statement in accordance with the Act as specified in the Act.	DOE projects ability to comply, because it will prepare the required environmental impact statement.
National Forest Organic Legislation (16 USC 475), Multiple-Use Sustained-Yield Act (16 USC 528-531), Forest and Rangeland Renewable Resources Planning and Research Acts, National Forest Management Act, and Renewable Resource Extension Act (16 USC 1600-1676 (36 CFR 261))	These Acts protect and improve National Forests that are established for outdoor recreation, range, timber, watershed, and fish and wildlife purposes.	DOE must obtain congressional approval for withdrawal of National Forest land for DOE use as a repository site. Access roads on National Forest land must be built in accordance with requirements defined by the U.S. Department of Agriculture. Permanent roads must be approved as part of the National Forest Transportation System.	DOE has determined that no National Forest land occurs at the reference repository location.	Statutes are not applicable at this site, because no National Forest land occurs at the reference repository location or vicinity.
National Trails System Act (16 USC 1241-1249)	The National Trails System Act establishes and protects National Recreation, National Scenic, and National Historic Trails.	If a National Trail is identified within the candidate repository area, DOE must determine if the project would be incompatible with the purposes of the trail.	A preliminary determination has been made that no National Trails occur at the reference repository location.	DOE projects ability to comply, because no National Trails exist at the reference repository location or vicinity.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 8 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
National Wildlife Refuge Administration Act of 1966 (16 USC 668dd, 668ee (50 CFR 25, 27, 28, and 29))	The National Wildlife Refuge Administration Act of 1966 establishes the National Wildlife Refuge System by consolidating authority over fish and wildlife conservation areas under the Secretary of the Interior, U.S. Fish and Wildlife Service.	DOE activities must not conflict with the major purposes for which the areas were established.	The Saddle Mountain National Wildlife Refuge is located approximately 10 kilometers (6.2 miles) north of the reference repository location. This area was made available to the U.S. Fish and Wildlife Service under a revocable permit from the DOE (Section 3.4.1). No significant impacts are expected from site-characterization or repository activities.	This statute is not applicable, because no wildlife refuge is located on the site.
Noise Control Act of 1972 and the Quiet Communities Act of 1978 (42 USC 4901)	The Noise Control Act authorizes the U.S. Environmental Protection Agency to prescribe regulations and guidelines for reduction of noise.	DOE must determine if Federal noise-emission standards can be met for equipment. Additional State or local requirements for equipment not covered by Federal standards must also be met. DOE must determine major noise source terms from equipment and distances to sensitive receptors (nearest human habitation).	DOE has determined that site-characterization and repository activities will be remote from the nearest human habitation (see Subsections 4.2.1.3.3 and 5.2.1.3.3).	DOE projects compliance with this Act due to the remoteness of site-characterization and repository activities from the nearest human habitation.
Organic Act of the National Park Service (16 USC 1 and 1901-1912 (36 CFR 9))	The Organic Act of the National Park Service serves to preserve National Parks and to leave them unimpaired for future generations with special emphasis on halting or regulating mining so as to prevent or minimize damage to the environmental resources.	DOE should avoid any land within the boundaries of a National Park from consideration as a repository site.	DOE has determined that the reference repository location and support facilities do not lie within the borders of a National Park.	This Act is not applicable, because the reference repository location does not lie within a National Park.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 9 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Resource Conservation and Recovery Act of 1976 (42 USC 6901-6987 (40 CFR 124, 260 through 266, 270, 280))	The Resource Conservation and Recovery Act promotes and protects health and environment by prohibiting open dumping on land, regulating treatment, storage, transportation, and disposal of hazardous wastes, and providing for the promulgation of guidelines for solid waste collection, transportation, separation, recovery, and disposal practices and systems.	DOE must comply with applicable Federal, State, interstate, and local requirements relating to the disposal or management of solid or hazardous wastes. DOE must classify project waste as hazardous or nonhazardous solid waste. Generators and transporters of hazardous waste must comply with U.S. Environmental Protection Agency and U.S. Department of Transportation regulations. All shipments of hazardous waste are subject to a manifest tracking system. Facilities that treat, store, or dispose of hazardous waste must obtain permits. New facilities cannot operate until a permit has been issued by the U.S. Environmental Protection Agency or authorized State agency. Nonhazardous wastes are regulated under applicable State, local, and regional solid waste plans.	DOE has made projected classification of wastes expected to be generated by site characterization and repository construction, operation, and closure. These wastes are primarily nonhazardous and include sewage treatment effluent, combustible solids (e.g., paper and cartons), excavated solids, including drill cuttings and freshwater drilling fluids. DOE has determined that landfills and other disposal facilities for hazardous and nonhazardous waste are available. DOE plans to use available landfills for nonhazardous wastes from site characterization. If any potentially hazardous waste is actually generated, DOE will conduct a chemical analysis to confirm its composition and support its classification as hazardous or nonhazardous. DOE will comply with manifest requirements.	DOE projects ability to comply with applicable State and Federal solid and hazardous waste requirements, based on the type and quantity of waste expected to be generated. DOE will utilize licensed transporter and facility for any hazardous waste that may be generated.
Rivers and Harbors Act (33 USC 401-413 (33 CFR 322))	The Rivers and Harbors Act prevents any alteration or modification of the course, location, conditions, or capacity of any channel of any navigable water of the United States without a permit.	DOE must obtain a permit from the U.S. Army Corps of Engineers if fill material is put into navigable waters.	A barge offloading facility may be required. Such a facility already exists adjacent to the Hanford Site and would require no dredging. DOE does not plan any modifications to navigable waters.	DOE projects ability to comply, because a barge facility is presently available adjacent to the Hanford Site.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 10 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Safe Drinking Water Act (42 USC 300f-300g-10 (40 CFR 122 and 146))	The Safe Drinking Water Act prevents pollution of underground sources of drinking water.	DOE must obtain an underground injection control permit or utilize a licensed underground injection well facility, if underground injection is chosen as a method of waste water disposal. DOE must comply with all Federal, State, and local requirements regarding drinking water if public water system is proposed.	Disposal of waste water by brine injection is not being considered. State drinking water requirements will be addressed as applicable.	DOE projects ability to comply, because the provisions of the Act and regulations relating to underground injection are not applicable to the reference repository location and because underground injection is not planned. The provisions of the Act relating to compliance with State and local drinking water requirements will be followed.
Taylor Grazing Act (43 USC 315-3160 (43 CFR 4100))	The Taylor Grazing Act creates, protects, and regulates Federal grazing districts to provide for the orderly use and development of rangeland.	If repository site or access is located on a U.S. Department of the Interior Bureau of Land Management-designated grazing district, DOE must apply for a right-of-way use or withdrawal of grazing district land.	DOE has determined that the reference repository location, support facilities, and access thereto are not located on public lands administered by the U.S. Department of the Interior Bureau of Land Management.	This Act is not applicable to the reference repository location. No Bureau of Land Management-designated grazing district occurs at the reference repository location, support facilities, or in the vicinity.
Wild and Scenic Rivers Act (16 USC 1271-1287)	The Wild and Scenic Rivers Act prohibits construction on or directly affecting any river that is designated a component of the National Wild and Scenic Rivers system, or on any river designated for addition to the system that would adversely affect the values of the National Wild and Scenic Rivers system.	DOE must determine if any rivers in the vicinity of the reference repository location are designated as a component of the National Wild and Scenic Rivers system or a potential addition to the system. If DOE finds a National Wild and Scenic River in the site vicinity, it must prepare an impact evaluation. If impacts are direct and adverse, DOE must advise the Secretary of the Interior and Congress.	DOE has reviewed the National Wild and Scenic Rivers list and has determined that no designated National Wild and Scenic River is located in the reference repository location or in the vicinity of repository support facilities.	DOE projects ability to comply, because no designated National Wild and Scenic River has been identified in the site vicinity or in the vicinity of support facilities.
Wild, Free-Roaming Horses and Burros Act (16 USC 1331-1340 (43 CFR 4700))	The Wild, Free-Roaming Horses and Burros Act protects all unbranded and unclaimed horses and burros on public lands of the United States.	DOE activities must avoid harm (including indirect effects) to wild, free-roaming horses and burros on public land.	DOE has determined that no wild horses or burros exist on the Hanford Site.	DOE projects compliance with this Act, because of the absence of these species from the Hanford Site.

Table 6-3. Application of major Federal environmental laws to the reference repository location on the Hanford Site (sheet 11 of 11)

Authority	Purpose and intent	Requirements	Compliance demonstrated/ actions planned	Projected ability to comply
Wilderness Act (16 USC 1131-1136), Federal Land Policy and Management Act (43 USC 1782)	These Acts establish a National Wilderness Preservation System for public recreational, scenic, scientific, educational, conservation, and historic use.	Roads, structures, installations, et cetera are prohibited in designated Wilderness Areas or Wilderness Study Areas. DOE must avoid siting the repository and repository access within Wilderness Areas, as well as within Wilderness Study Areas until Congress has made a final determination whether to include them permanently as Wilderness Areas.	No designated Wilderness Areas or Wilderness Study Areas have been identified at the exploratory shaft or geologic repository operations area locations.	DOE projects ability to comply, because no designated Wilderness Areas are located at or near the reference repository location.

NOTE: DOE = U.S. Department of Energy.

The following list identifies key State of Washington and local environmental regulations that may apply to a repository at the Hanford Site.

- Archaeology and historic preservation (RCW 27.34, 27.53; WAC 25).
- Benton-Franklin-Walla Walla Air Pollution Control Authority (see also Table 6-3, Clean Air Act).
- Hazardous waste disposal (RCW 70.105; WAC 173-303) (see also Table 6-3, Resource Conservation and Recovery Act).
- Hydraulics project (RCW 75.20.100; WAC 220-110).
- Noise Control Act of 1974 (RCW 70.107; WAC 173-60 through 70) (see also Table 6-3, Noise Control Act).
- Pollution Disclosure Act of 1971 (RCW 90.52; WAC 173-40).
- Public water supply (RCW 43.20) (see also Table 6-3, Safe Drinking Water Act).
- Radioactive waste (RCW 43.200).
- Shoreline Management Act of 1971 (RCW 90.58; WAC 173-16 through 28).
- State Environmental Policy Act (RCW 43.21C; WAC 197-10).
- Washington Clean Air Act (RCW 70.94; WAC 173-400 through 495) (see also Table 6-3, Clean Air Act).
- Water rights* (RCW 90.03, 90.14, 90.44, 90.16).
- Water Pollution Control Act (RCW 90.48; WAC 173-216 through 225) (see also Table 6-3, Clean Water Act).

6.2.1.6.4 Favorable condition

"(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic technical, social, economic, and environmental factors."

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*Although the U.S. Department of Energy believes it has a federally reserved water right sufficient to conduct site characterization and repository operation, it has agreed that in the spirit of cooperation and as a matter of comity, the U.S. Department of Energy will submit a permit application for the use of water for its characterization activities to the appropriate State of Washington agency if the reference repository location were approved for characterization.

This favorable condition is expected to be present at the reference repository location. Current information suggests that, during all phases of repository activity, compliance with applicable environmental regulations would achieve acceptable levels of environmental protection.

The potential for significant adverse environmental impacts as a result of site characterization and locating a repository on the Hanford Site is discussed in Sections 4.2 and 5.2. The U.S. Department of Energy believes that a repository can be sited, constructed, and operated at the reference repository location in a manner that assures the environment would be adequately protected in compliance with this guideline. A final conclusion will be reached after additional environmental studies are conducted. The repository would be designed to mitigate environmental impacts to the extent reasonably achievable and to meet applicable regulations. Documentation of site acceptability under this guideline would be included in an environmental impact statement, which would accompany a site-recommendation report, if the reference repository location were selected as a repository site.

6.2.1.6.5 Potentially adverse condition

"(1) Projected major conflict with applicable Federal, State, or local environmental requirements."

Repository activities at the reference repository location are not expected to be in major conflict with Federal, State, or local environmental regulations; therefore, this potentially adverse condition is not present.

Environmental analyses conducted for the U.S. Department of Energy nuclear activities on the Hanford Site (ERDA, 1975; DOE, 1982a, 1983a) suggest there would not be a major conflict with applicable environmental regulations if a repository were located at the Hanford Site.

6.2.1.6.6 Potentially adverse condition

"(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated."

This potentially adverse condition is not considered present, since repository activities at the reference repository location are not projected to create significant adverse environmental impacts that cannot be avoided or mitigated.

The potential significant adverse environmental impact of locating a repository on the Hanford Site is discussed in Section 5.2. Currently, there are no projected significant adverse environmental impacts that cannot be avoided or mitigated. Plans for repository activity would take into account potential impacts, and mitigation measures would be factored into repository design and operation decisions.

6.2.1.6.7 Potentially adverse condition

"(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land."

This potentially adverse condition is not present at the reference repository location. No adverse environmental impacts on nationally protected resources are projected to result from the repository or its support facilities.

The reference repository location is situated on the U.S. Department of Energy-controlled 1,500-square-kilometer (570-square-mile) Hanford Site, which has been dedicated to nuclear activities since 1943. The presence of a repository on the Hanford Site does not present any significant adverse environmental impacts to any nationally protected natural resources. The Columbia and Yakima Rivers are not being considered for inclusion in the Wild and Scenic Rivers system, although the Columbia River had been proposed and was subsequently withdrawn (Subsection 6.2.1.6.11).

6.2.1.6.8 Potentially adverse condition

"(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area."

This potentially adverse condition is not present at the reference repository location, since there are (1) no significant protected resource areas within or adjacent to the reference repository location and (2) no significant adverse environmental impacts from repository activities are projected.

There are no significant State or regionally protected resource areas in the vicinity of the reference repository location. The presence of a repository on the Hanford Site would not impact any such resource area (Subsection 6.2.1.6.11).

6.2.1.6.9 Potentially adverse condition

"(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest."

This potentially adverse condition is not present at the reference repository location, since there are (1) no known significant Native American resources within or immediately adjacent to the reference repository location and (2) no significant adverse impacts are projected for resources distant from the reference repository location.

In 1981 and 1982, archaeological field surveys were conducted in the reference repository location where surface activities could take place. These studies concluded that none of the repository activities would have an effect on significant Native American cultural resources (Rice, 1984a, 1984b). There are areas of significant Native American resources on the Hanford Site, primarily along the Columbia River 12 kilometers (7 miles) from the reference repository location at the nearest point, and in the vicinity of the Gable Mountain archaeological locality 7 kilometers (4.5 miles) from the reference repository location. However, the distance of the repository site from these resources indicates there would be no projected significant adverse environmental impacts.

6.2.1.6.10 Potentially adverse condition

"(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities."

This potentially adverse condition is not present at the reference repository location, since there are no known threatened or endangered species inhabiting the site.

No federally recognized threatened or endangered plant species are known to exist on the reference repository location. No federally recognized threatened or endangered animal species are known to nest on or use the reference repository location as critical habitat. There are, however, a few animal species that are State recognized and are candidates for Federal listing that do nest on or near the reference repository location (see Subsection 3.4.2.5). Further studies on threatened or endangered species would be conducted during site characterization (see Subsection 4.1.2.3).

6.2.1.6.11 Disqualifying conditions

"Any of the following conditions shall disqualify a site:

"(1) During repository siting, construction, operation, closure, or decommissioning the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors.

"(2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.

"(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated use resource-preservation of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act."

The siting of a repository at the reference repository location is not projected to have unacceptable adverse impacts on the quality of the environment. The two primary factors that indicate these disqualifying conditions are not present at the reference repository location are (1) no adverse environmental impacts have been projected that could not be mitigated to an acceptable degree, including the absence of any federally recognized threatened and endangered species at the reference repository location and (2) significant Federal- or State-protected resources do not exist at the reference repository location. The nearest Federal- or State-protected resource is the Columbia National Wildlife Refuge located 20 kilometers (12.5 miles) north of the reference repository location. Therefore, the evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2).

The reference repository location is situated on the U.S. Department of Energy-controlled 1,500-square-kilometer (570-square-mile) Hanford Site, which has been dedicated to nuclear activities since 1943. Environmental analyses conducted for nuclear activities administered under the U.S. Department of Energy suggest that compliance with applicable environmental laws and regulatory requirements would not be a problem if a repository were located at the Hanford Site. No adverse environmental impacts have been found that threaten the health or welfare of the public or the quality of the environment, which cannot be mitigated (ERDA, 1975, pp. III.1-1 through III.1-47; DOE, 1982a, 1982c, 1983a). Also, the Puget

Sound Power and Light Company and the Washington Public Power Supply System have independently conducted environmental analyses in accordance with U.S. Nuclear Regulatory Commission criteria (NRC, 1984) at the Hanford Site for the purpose of siting, constructing, and operating nuclear power-plants. No major environmental impacts, which could not be mitigated, were identified (PSPL, 1981, pp. 4-1 through 4.5-5; WPPSS, 1977a, pp. 4.1-1 through 4.5-2). Impacts associated with building a repository on the Hanford Site are discussed in Section 5.2.

Repository construction and operation would have minimal expected effects on the local ecosystem. Expected adverse impacts to the habitat would include the loss of approximately 80 hectares (200 acres) of habitat due to construction of surface facilities and the temporary loss of habitat during construction of utility rights-of-way. Adverse impacts to the native biota would include minimal levels of disturbance due to the presence and noise of repository activities.

The significant impacts at the repository site would result from the selective clearing and grading of approximately 80 hectares (200 acres) of shrub-steppe terrain (i.e., all of the central process area plus an area outside the central process area for a parking lot, helicopter landing pad, and a mine-water percolation pond). Though the permanent loss of this habitat would be significant on a local scale, the area selected for surface facilities would not be ecologically unique or sensitive or significantly impact the production capacity of the regional habitat.

The temporary loss of habitat during construction of utility rights-of-way would be significantly influenced by the selection of the routes. Incoming utilities would consist of water, electric power, and telephone. Water would be supplied from the Columbia River by an existing river pump station, which would be modified by the addition of new pumps. A buried pipeline would connect these pumps to the repository surface facilities. Two transmission lines, routed over separate parallel rights-of-way, would connect the repository to the Hanford Site power system, and an overhead telephone line would connect the repository surface facilities to the Hanford Site telephone network. This temporary loss of habitat would be minimized through the careful location and timing of construction activities. Available techniques would be used to reclaim disturbed lands.

Throughout the design, construction, and operation of the repository, efforts would be made to reduce significant adverse impacts on the habitat. Studies would be performed to characterize the surrounding habitat to assess and support the minimization of adverse impacts. Operational activities would include the minimization of vegetation removal. Topsoil stripped would be stockpiled for future replacement and planting. Access to any known or potential areas of sensitive habitat would be limited. Use of Hanford Site roads and utilities would reduce environmental impacts.

Adverse impacts to the native biota are expected to be minimal and would include minimal levels of disturbance due to the presence and noise of repository activities. One area of potential impact could be the disturbance of native fauna (including both surface facility and utility activities). These activities could damage potential nest habitat or cause abandonment of nests. Of primary concern is the potential for impact to federally recognized threatened or endangered animal species. At this time, no such species are known to nest within the reference repository location (FWS, 1984) (see Subsection 3.4.2.5). During field investigations, a threatened bird species, the bald eagle (Haliaeetus leucocephalus), and an endangered bird species, the peregrine falcon (Falco peregrinus) (FWS, 1985b), were sighted infrequently within the reference repository location boundaries; however, their presence is not common. Three additional bird species that nest in the vicinity of the reference repository location are now being considered as potential candidates for protection on the Federal threatened and endangered species list. These are the ferruginous hawk (Buteo regalis), the Swainson's hawk (Buteo swainsoni), and the long-billed curlew (Numenius americanus) (FWS, 1985b). Although not officially protected, these species are included in biological investigations. Disturbance to native fauna would be minimized through planning and monitoring of repository and utility construction and programmatic control of unnecessary access to impact sensitive areas.

Adverse impacts to native flora resulting from uncontrolled physical disturbance are expected to be minimal. Again, of primary concern is the potential for impact to federally recognized threatened or endangered plant species. At this time, no such plant species are known to exist on the reference repository location (FWS, 1984). Several vascular plant species that do occur on the Hanford Site are being considered by the U.S. Fish and Wildlife Service as threatened species. Included in this category are the Columbia milk-vetch (Astragalus columbianus), the Hood River milk-vetch (Astragalus hoodianus), and the Persistentsepal yellowcress (Rorippa calycina Variety columbiae) (FWS, 1985a). Two State-sensitive species, gray cryptantha (Cryptantha leucuphasa) and a sandwort (Arenaria franko-linii Variety thompsonii) have been located at the Hanford Site near the reference repository location (State of Washington, 1984, 1985). The presence of these or other potentially sensitive species on the reference repository location has not been established during recent investigations; however, these investigations are continuing. Disturbance to native flora would be minimized through planning and monitoring of repository and utility construction and programmatic control of unnecessary access to impact sensitive areas.

Neither construction nor operation of the proposed repository is expected to have any measurable effects on local or regional surface-water quality due to the absence of discharges to surface waters. Surface- and ground-water impacts are reviewed in Subsection 5.2.1.2.

The reference repository location is not located within the boundaries of a significant nationally protected natural resource nor would activities at the reference repository location irreconcilably conflict with designated uses of any protected resources encompassed by the disqualifying condition. Some areas of the Hanford Site are managed by the U.S. Department of Energy to act as buffer zones for nuclear activities, but are also available for other programmatic uses. The closest buffer area is 130 square kilometers (50 square miles) of Hanford Site lands north of the Columbia River, designated as the Saddle Mountain National Wildlife Refuge (see Fig. 3-37) and managed under revocable permit from the U.S. Department of Energy by the U.S. Fish and Wildlife Service. The closest protected area is the Columbia National Wildlife Refuge 20 kilometers (13 miles) north of the reference repository location.

The Hanford reach of the Columbia River, which includes the entire length of the river within the Hanford Site, is the last undammed section of the Columbia River. This portion of the river was proposed as a potential wild, scenic, or recreational river under the Wild and Scenic Rivers Act (USDA, 1970, p. 16693). It has since been removed from consideration (Wild and Scenic Rivers Act of 1968, as amended). The reference repository location is approximately 7 kilometers (4 miles) from the Columbia River and no significant impacts on the river ecosystem are expected from repository activity. The Arid Lands Ecology Reserve on the Hanford Site is a 310-square-kilometer (120-square-mile) tract set aside as a buffer zone for the protection and study of native plant and animal ecosystems, consistent with nuclear activities on the Hanford Site. This area is managed by the U.S. Department of Energy. Repository surface facilities or the restricted area would not be located within the boundaries of this reserve. The presence of a repository at the reference repository location would not present irreconcilable differences with the current and planned uses of these areas.

The closest State-managed natural area is 220 square kilometers (85 square miles) of Hanford Site land north-northeast of the Columbia River, the Wahluke Wildlife Recreation Area (see Fig. 3-37). This area, approximately 17 kilometers (11 miles) from the reference repository location, is managed for the U.S. Department of Energy under revocable permit by the State of Washington Department of Game. The presence of a repository on the Hanford Site is not expected to present irreconcilable differences with the use of this area. This area was set aside by the U.S. Department of Energy, and continues to serve as a buffer zone around the U.S. Department of Energy operations and could potentially be considered for locating future program facilities.

Shipments of nuclear waste to the repository would be in accordance with applicable Federal regulations (Appendix A). The projected radiological impacts of nuclear waste transportation are small in comparison to doses from naturally occurring radioactive materials. The potential radiological consequences of transportation accidents are controlled primarily by the highly damage-resistant shipping containers required under current Federal regulations. Although these radiological impacts are of less significance, they are directly related to transportation distance. The localized environmental impacts due to transportation would be determined in part by the availability and capacity of existing highway and rail routes and the existence of heavily populated areas along these routes (Subsection 6.2.1.8). If selected as a repository, an environmental impact statement would be prepared to support a site-recommendation report and would provide information on the environmental impacts of waste transportation.

6.2.1.6.12 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). The following factors support this finding.

- The environmental analyses conducted for the U.S. Department of Energy nuclear activities suggest that compliance with environmental laws and regulatory requirements would not be a problem if a repository were located at the reference repository location.

- The reference repository location is not within the boundaries of a nationally protected natural resource.

- The construction and operation of a repository would not be inconsistent with current and planned land use.

- No adverse environmental impacts on the quality of the environment have been identified that cannot be mitigated.

- No federally recognized threatened or endangered animal species are known to nest on or use the reference repository location as critical habitat.

- No federally recognized threatened or endangered plant species are known to exist on the reference repository location.

- There are areas of significant Native American resources on the Hanford Site; however, the distance from the repository to these resources indicates there would be no significant adverse impacts.

- Significant Federal- or State-protected resources do not exist at or near the reference repository location; hence, no conflicts exist.

Uncertainties associated with these findings include the following:

- Impact projections are based on a conceptual repository design.

- Three avian species that nest in the vicinity of the reference repository location are State recognized and are candidates for the Federal threatened or endangered species list.

6.2.1.7 Socioeconomic impacts (Section 960.5-2-6)

6.2.1.7.1 Qualifying condition

"The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes; and, (2) the requirements specified in Section 960.5-1(a)(2) can be met."

6.2.1.7.2 Evaluation process

The area surrounding the Hanford Site had an unusual growth history from 1973 to 1981 that has been dominated, and primarily influenced, by growth in energy-related projects and the construction of nuclear powerplants. After 1981, the rapid and unplanned slowdown of major construction projects dramatically reversed a decade-long pattern of exceptionally rapid growth.

The socioeconomic impacts of a repository on the Hanford Site are not expected to be significant. The overall size of the repository work force and the resource requirements of the project are quite small (see Subsection 5.1.1.2) relative to the scope of development activities the area has experienced in the past (see Section 3.6). The work force requirements during the first 20 years of repository development imply annual rates of change in projected baseline employment and population of only approximately 1 percent per year over the first 5 years of repository construction. This rate of growth could be absorbed without significant adverse impacts on the study region.

Information on expected effects of repository activities on socioeconomic conditions are presented in Section 5.2.3. Additional information can be found in a report by Cluett et al. (1984).

6.2.1.7.3 Favorable condition

"(1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand."

This favorable condition is expected in the communities where repository support staff could reside. The local communities presently have existing services to absorb project-related population changes.

Due to the extraordinarily high growth experienced in the area between 1973 and 1981, planning and development led to increased capacities in community services and housing (see Section 3.6). However, the unplanned cutback in the job market in 1981 left the area with capacities beyond the needs of the current conditions (Cluett et al., 1984). The area surrounding the Hanford Site is expected to have a large absorptive capacity into the 1990's (see Section 5.2.3). This means that employment and population growth caused by repository activities could be readily assimilated by the area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress.

6.2.1.7.4 Favorable condition

"(2) Availability of an adequate labor force in the affected area."

This favorable condition is not present since miners are not locally available.

Detailed information on the composition of the needed work force, especially during repository construction, is not available. However, since the size of the construction force, even during the peak years, would be approximately 1,100, it is unlikely to exceed the regional availability of construction workers with various skills. (Section 3.6.1 addresses the large local population growth observed between 1973 and 1981 due to construction activity on the Washington Public Power Supply System nuclear projects.) Lack of mining activity in the area means that miners are not likely to be available locally. However, the relatively small number of in-migrating miners (less than 400) required, compared to the population of the area surrounding the Hanford Site, would have little or no impact on the socioeconomic conditions of the region.

6.2.1.7.5 Favorable condition

"(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area."

This favorable condition is present, since the projected employment, business, and community opportunities will strengthen the local community.

The employment and population growth implied by the repository activities should represent an opportunity for the area to reach fuller use of its human and physical resources. These resources are presently unemployed or underutilized due to the deferral and (or) completion of major construction projects in the area.

6.2.1.7.6 Favorable condition

"(4) No projected substantial disruption of primary sectors of the economy of the affected area."

The local economy would not be substantially disrupted by repository-related needs; therefore, this favorable condition is present.

A repository would likely provide additional stability to economic conditions in the area as well as to the perception by residents of stability and the relative permanence of employment opportunity (see Subsection 5.2.3.2).

6.2.1.7.7 Potentially adverse condition

"(1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area."

This potentially adverse condition is not present, since the affected community could absorb these community and governmental impacts. The most likely increased population growth is estimated to result in peak annual growth rates of 2.4 percent for Richland, Washington, 1.1 percent for Kennewick, Washington, 0.3 percent for Pasco, Washington, 3.2 percent for West Richland, Washington, and 2.4 percent for Benton City, Washington.

Further, due to the recent slowdown in the economic sector of the affected area and resulting population out-migration, there is an underutilization of community services, excess capacity in housing and schools, etc. (see Section 3.6.3). Therefore, a repository represents an opportunity for the area to reach fuller utilization of its resources. Socioeconomic impacts of a repository are projected to be positive.

6.2.1.7.8 Potentially adverse condition

"(2) Lack of an adequate labor force in the affected area."

This potentially adverse condition is present in the affected area. An adequate work force of miners is not presently available.

The affected area has a highly skilled work force available, with the exception of miners (see Section 3.6.2 and Subsection 6.2.1.7.4). Miners will need to in-migrate (see Section 5.2.3).

6.2.1.7.9 Potentially adverse condition

"(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area."

This potentially adverse condition is not present at the reference repository location. The U.S. Department of Energy believes that it has a reserved water right for all water needed to develop and operate a repository. Should the reference repository location be selected for construction and operation of a repository, the U.S. Department of Energy may determine, as a matter of cooperation and comity, to apply for a water permit for required water. In any event, however, the quantity of water required (average demand of 2.6 cubic meters per minute (700 gallons per minute)) would be a small percentage of water usage at the Hanford Site (Subsection 6.3.3.3.5) and would not be expected to have significant or adverse effect on future development of the area. It is likely that the raw water system used to supply the 200 Areas of the Hanford Site has capacity to serve the repository.

6.2.1.7.10 Potentially adverse condition

"(4) Potential for major disruptions of primary sectors of the economy of the affected area."

This potentially adverse condition is not present, since the study region economy could absorb the community, business, and governmental services related to repository construction and operation.

The potential for major disruptions of primary sectors of the economy of the affected area is very low (see Section 3.6.2 and Subsection 5.2.3.2). The local economy, including such major economic sectors as agriculture, retail trade and services, and tourism would not be substantially disrupted by repository-related needs.

6.2.1.7.11 Disqualifying condition

"A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite supplies "presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures."

Based on proposed construction, operation, and closure, a repository is not expected to degrade significantly the quality or reduce the quantities from major water sources off the repository site. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Chapter 5 identified the facilities to support repository development, in addition to identifying the environmental effects of locating a repository at the reference repository location. Based on the information provided in Chapter 5, repository construction, operation, and closure would not degrade water quality.

The deep ground water at repository depth is not suitable for human consumption or crop irrigation (see Subsection 6.3.1.1.9). This deep ground water contains natural chemical constituents (e.g., high fluoride, sodium, and boron concentrations), which require removal or treatment before most use.

The second part of the above disqualifying condition deals with impacting water quantities. Availability of water supply is not expected to be a problem for the reference repository location (see Subsections 6.2.1.7.9 and 6.3.3.3.5). The water quantity needed for repository construction, operation, and closure would be a small percentage of water use at the Hanford Site and is a small component of the total Columbia River flow. Therefore, no significant reduction of water quantity from major sources of water supplies off the Hanford Site is expected.

6.2.1.7.12 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This finding is based on the following factors.

- Projected employment and population growth caused by repository activities could be readily assimilated by the area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress on the community services and facilities.

- Projected employment, business, and community opportunities would strengthen the local community.

- Growth in the primary sectors of employment is expected to continue in the future without disruption due to repository-related needs.

- Availability of water supply is not expected to be a problem for the reference repository location.

- A technically qualified work force (except for miners) is located nearby in the Tri-Cities and the surrounding areas.

Some data for socioeconomic evaluations contain uncertainties requiring that assumptions be made, and thus result in subjective evaluations. Among the sources of uncertainty are the following:

- Detailed information on the size and composition of the needed work force, especially during repository construction, is not available.

- Future characteristics of the socioeconomic conditions in the affected area are difficult to forecast accurately.

6.2.1.8 Transportation (Section 960.5-2-7)

6.2.1.8.1 Qualifying condition

"The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in Section 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met."

6.2.1.8.2 Evaluation process

Evaluation of compliance with the transportation guideline by the reference repository location is based on a compilation of information on existing transportation systems, repository planning, and preliminary assessments of transportation impacts (see Sections 3.5, 5.2.2, and Appendix A). This information is categorized as follows:

- Characteristics of existing local and regional transportation routes.

- Current transportation capabilities and practices.

- Transportation cost and risk analyses for potentially acceptable repository sites.

- Conceptual planning for repository access routes.

- Projected numbers and capacities of shipments.

To ensure that all sites were evaluated in a consistent manner, a common set of criteria was developed by the U.S. Department of Energy. Where possible, the criteria were quantified (Appendix A). These criteria will be identified as required in the following sections to explain the positions taken.

Some of the relevant data for transportation evaluations contain uncertainties requiring that assumptions and subjective evaluations be made. Some sources of uncertainty are listed below.

- Designs of the repository and its associated access routes are preliminary.

- Future characteristics of the transportation system (e.g., physical condition, traffic density) during repository operation are difficult to forecast accurately.

- Percentages of nuclear waste shipments by a given mode (e.g., truck, rail) or over a specific route cannot be accurately predicted because of many factors outside the jurisdiction of the U.S. Department of Energy.

- Detailed design information on new generations of nuclear waste shipping casks that are planned for shipments to a repository is not available.

Information presented in Sections 3.5 and 5.2.2 has been used to evaluate the favorable, potentially adverse, and qualifying conditions of the transportation guideline. Although the analyses are preliminary and subject to the data uncertainties identified previously, they are adequate for supporting findings on the transportation guidelines.

6.2.1.8.3 Favorable condition

"(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

"(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

"(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

"(iii) Cuts, fills, tunnels, or bridges are not required.

"(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.

"(v) Such routes bypass local cities and towns."

This favorable condition is present for proposed access routes to the reference repository location. Only one of the characteristics need be present to meet this favorable condition. It should be noted that access routes to the reference repository location meet all five favorable conditions.

The proposed access routes from local existing highways and railroads to the proposed repository surface facilities are short extensions of the existing highway and railroad networks that serve the Hanford Site (see Fig. 3-43 through 3-46). These access routes are each less than 5 kilometers (3 miles) in length; these distance estimates are upper-limit values, since specific access routes have not been designed. Access routes are economical to construct because they are short, and surface conditions (e.g., soil-bearing capacity, topography, drainage) require only minimal grading or other surface-preparation work. The construction costs for the necessary rail and truck access routes are expected to total less than 6 million dollars. Federal condemnation is not required to acquire rights-of-way, since the proposed access routes lie entirely within the Hanford Site, which is owned by the Federal Government. If highway access from Route 240 to the proposed repository site was provided, only the first portion of such an access would lie on the State of Washington easement. The U.S. Department of Energy has the right to provide a new intersection with Route 240 under existing easements; such an intersection would be designed to meet the State of Washington design standards (see Subsection 6.2.1.3). No tunnels or bridges would be required, and the topography is sufficiently flat that little cutting and filling would be required (see Section 3.1 and Subsection 6.3.3.1.3). The flat topography, together with the abundant open land surrounding the proposed repository site, permits access route layouts that are free of sharp curves, steep grades, and potential for landslides or rockslides. Proposed access routes from existing highway and railroad networks are remote from cities and towns.

6.2.1.8.4 Favorable condition

"(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction."

This favorable condition is present, since nearby highways and rail lines exist that are considered adequate to serve the repository without significant upgrading or reconstruction. The measure of proximity used for evaluating the presence of this favorable condition is the distance from the outer end of the repository access road (or rail access spur) to the nearest point on an existing highway (or railroad) beyond which upgrading is not required. Since such upgrading is not deemed necessary for existing highway and rail lines that would serve a repository at the reference repository location, the measure of proximity for this favorable condition is zero for highway and rail.

The local and regional highway network provides ready access from the vicinity of the proposed repository site to the two major interstate highways on which materials being transported to the repository by truck could travel (see Section 3.5 and Fig. 3-44). Expected traffic enroute to the reference repository location is small compared to the volume of truck traffic routinely carried by these highways. Weight restrictions below legal-weight truck limits are unlikely to be imposed. Thus, no significant upgrading or reconstruction of local and regional highways appears justified specifically on the basis of transportation associated with the repository.

Regional highway access to Interstate 84 will soon be improved by new segments of Interstates 82 and 182, which are under construction (see Fig. 3-45). The new Interstate 82 will connect directly with Interstate 84 and with the new Interstate 182; these new interstate highways will permit shipment via interstate highways all the way to the south end of Richland, Washington.

The local railroad network, which is described in Section 3.5, provides ready access to two major railroads with classification and switching yards at Pasco, Washington, and Hinkle, Oregon. Analogous to the existing local highway situation, neither shipment volumes nor railcar weights associated with repository shipments appear to justify significant upgrading or reconstruction of the local railroad networks.

6.2.1.8.5 Favorable condition

"(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system."

This favorable condition is present, since a nearby highway system exists that provides access to the national transportation system. The favorable condition is considered to be present if proximity to the national highway system or the national rail system exists. The measure of highway proximity used for evaluating the presence of this favorable condition is the distance from the outer end of the repository access road to the point of connection with a state, United States, or interstate highway that provides access to the national network. Up to approximately 48 kilometers (30 miles) are considered to be a reasonably proximate distance for the favorable condition. Since the repository access road could connect directly with an existing State highway adjacent to the reference repository location, the measure of highway proximity is zero for this favorable condition. The local State highway network provides access to the national transportation system, since it connects with Interstate 90 to the north and Interstate 84 to the south.

The measure of railroad proximity used for evaluating the presence of this favorable condition is the distance from the outer end of the railroad access spur to the point of connection with a mainline railroad that provides access to the national network. Up to approximately 48 kilometers (30 miles) are considered to be a reasonably proximate distance for the favorable condition. The rail access spur would connect with an existing nonmainline railroad system; the rail transportation distance is approximately 78 kilometers (48 miles) over this existing system to its point of connection with a mainline railroad at Pasco, Washington. A second point of connection with a mainline railroad is available at the Hinkle, Oregon, classification yard.

A transloading facility for barge shipments up the Columbia River is located at a Port of Benton facility approximately 32 kilometers (20 miles) from the proposed repository site. Proximity to an inland waterway has not been considered in applying this favorable condition, since barge shipments would have to be transferred to rail or truck. Materials transported by barge up the Columbia River could include repository equipment and construction and operating supplies; barge transport of a small fraction of nuclear waste shipments remains an option.

6.2.1.8.6 Favorable condition

"(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required."

A finding on this favorable condition cannot be made based solely on Hanford Site regional data, since a comparison of the candidate sites is needed to determine the one having the minimum number of interchange points. The chosen method of applying this favorable condition is to credit each site with at least one railroad interchange point at the point where the site spur joins the mainline railroad, and to count all other interchanges within a 200-kilometer (125-mile) radius from the site. The site with the fewest interchanges is considered to have the favorable condition present. Therefore, the finding on this favorable condition is included in the Chapter 7 site comparisons.

The Hanford Site is served by two major railroads, Union Pacific and Burlington Northern, with switching capability at two nearby classification yards located at Hinkle, Oregon, and Pasco, Washington, respectively (see Fig. 3-43). On the Burlington Northern route, the closest interchange point beyond the Pasco classification yard is located at Spokane, Washington, which is about 220 kilometers (136 miles) from Pasco. On the Union Pacific route, there are two interchange points between the Hinkle classification yard and Boise, Idaho; the first of these interchanges is at LaGrande, Oregon, which is about 130 kilometers (80 miles) from Hinkle, and the second is at Nampa, Idaho, which is about 370 kilometers (230 miles) from Hinkle. On the Union Pacific route, there is also an additional interchange point, located at Wallula, Washington, between the Hinkle classification yard and the Hanford Site.

6.2.1.8.7 Favorable condition

"(5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories."

This favorable condition does not appear to be present at the reference repository location as long as truly comparable siting options exist at locations closer to the projected waste sources in the central and eastern United States (Fig. 6-2). The chosen method of applying this favorable condition is to assume that all siting options are comparable and to assign a finding of present for this favorable condition to the single candidate site having the lowest total projected life-cycle transportation cost and risk. Therefore, the finding on this favorable condition is included in the Chapter 7 site comparisons.

Total projected life-cycle transportation costs and risks for several potential candidate sites are shown in Appendix A. Comparison of the cost and risk values shows a range of almost a factor of two. That is, transportation costs and risks for the most distant site (the reference repository location) are almost twice those of the site nearest the projected waste sources. The life-cycle transportation cost for the reference repository location (roughly 1.3 to 1.7 billion dollars, depending on transportation mode assumptions) is smaller than the estimated repository lifecycle cost of roughly 12 billion dollars. Population radiation exposures due to transportation are estimated to be no more than approximately 0.03 percent of those attributable to background radiation. Fatalities associated with transportation of radioactive material to a repository at the reference repository location are expected to be less than approximately 0.05 percent of the current annual national total for commercial freight (McSweeney et al., 1984). The comparisons of life-cycle transportation costs and risks for the candidate repository sites show less significant differences among sites if the alternative monitored

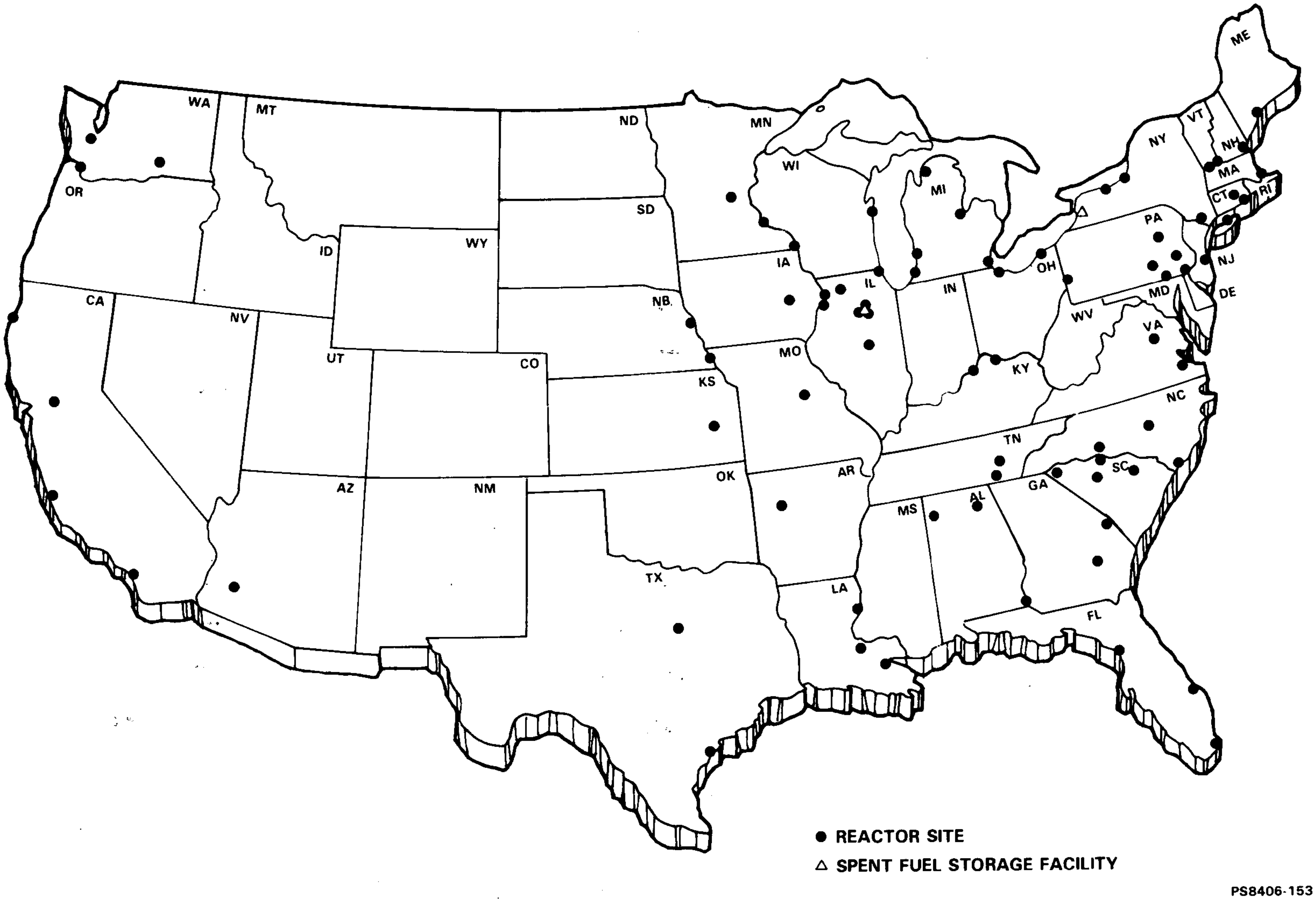


Figure 6-2. Location of existing and planned commercial nuclear reactors and storage facilities with light water reactor commercial spent fuel (after DOE, 1983b, p. 18).

retrievable storage facility scenario were factored into the analyses (Appendix A). These differences among sites would be further reduced in significance if candidate locations for the second repository were included in the analyses.

6.2.1.8.8 Favorable condition

"(6) Availability of regional and local carriers--truck, rail, and water--which have the capability and are willing to handle waste shipments to the repository."

This favorable condition is present for the reference repository location. For each transport mode (truck, rail, and barge), several competing companies already provide routine service to the Tri-Cities area.

The Tri-Cities area is served by 18 local, regional, and national trucking lines, 2 major railroads, and 7 major barge lines. Rail service from the Tri-Cities area to the Hanford Site is provided by a U.S. Department of Energy contractor using U.S. Department of Energy-owned equipment and tracks. Waste shipments destined for the repository will most likely be transported by national truck and rail carriers, as opposed to smaller regional firms. The two railroads and many of the trucking lines that serve the Tri-Cities area are associated with national networks, and have the capability to handle repository waste shipments. The willingness of these carriers to handle waste shipments does not appear to be in question, but there is some uncertainty in the rate levels that will be established.

6.2.1.8.9 Favorable condition

"(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States."

This favorable condition is present for the reference repository location, since no legal impediments to waste transportation exist within the State of Washington or adjoining States. The U.S. Department of Transportation regulation of highway routing of radioactive materials has been established as valid by the U.S. Supreme Court (Appendix A). Therefore, the only legal impediment would be a State (including Indian tribal authorities) or local routing rule that renders compliance with U.S. Department of Transportation regulations impossible, but is found not to be preempted under provisions of the Hazardous Materials Transportation Act (Appendix A). If such a finding cannot be made, any State (including Indian trival authorities) or local routing rule that prevents or seriously impedes compliance with U.S. Department of Transportation regulations is preempted. State routing agencies, including Indian tribal authorities, are authorized by U.S. Department of Transportation regulations to designate alternative preferred highway routes in consultation with other affected jurisdictions, including local and adjacent State jurisdictions.

Two attempts to establish legal impediments to nuclear waste transportation have been made within the State of Washington in recent years, but neither of these would constitute a legal impediment under the above definition. The State of Washington passed legislation (later ruled unconstitutional) that would have restricted shipments to a commercial radioactive waste-disposal site located at the Hanford Site on land leased from the State. The Yakima Indian Nation, located within the State of Washington, passed a resolution against radioactive waste transportation through their reservation. A formal nonpreemption ruling must be sought and obtained from the U.S. Department of Transportation before this resolution will be considered to be a legal impediment in applying the favorable condition.

6.2.1.8.10 Favorable condition

"(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed."

This favorable condition is present for waste shipments to the reference repository location. Plans, procedures, and capabilities for response to radioactive waste-transportation accidents have already been developed by the State of Washington, in conjunction with previous radioactive material shipments. Most of the previous radioactive material shipments have had different characteristics than the proposed spent fuel and high-level waste shipments to a repository. However, the basic types of plans, procedures, and capabilities required for emergency response are not expected to change significantly. Further evaluation of emergency response preparedness may be warranted by the increased shipment frequencies if the reference repository location were selected as a repository site.

The State of Washington has a radioactive material-control program, and recognizes the State and local primary responsibility for responding to transportation accidents involving radioactive material. The State has established emergency teams and procedures for dealing with such accidents and agreements with the U.S. Department of Energy regarding additional technical support, if needed. The Federal Emergency Management Agency is coordinating the development of a Federal response plan covering all types of radiological incidents, and has provided guidance to State and local governments for preparing their own radiological emergency response plans that cover transportation accidents.

6.2.1.8.11 Favorable condition

"(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences."

This favorable condition is present for the region encompassing the reference repository location. The region used for other transportation analyses was expanded to include points at which a routing change could be made if warranted by weather conditions along the intended route. Transportation disruptions were considered to be significant if they jeopardized the ability to accomplish planned annual shipment rates. Disruptions of transportation due to weather conditions are uncommon in the region. Major highway closures due to adverse weather conditions are typically infrequent and of short duration.

The meteorology of the Hanford Site and vicinity is described in Section 3.4.3, and transportation disruptions due to weather are discussed in Section 3.5.2. The truck-transportation mode is the one most prone to interruption due to weather. Weather conditions in southeastern Washington most likely to cause highway closure are high-velocity wind gusts, causing poor visibility due to airborne dust and debris; and snow and (or) ice, causing poor traction for vehicles. These conditions are generally seasonal (e.g., strong winds in spring; snow and ice in winter) and do not cause highway closures with sufficient frequency to be considered routine. Highway closures due to weather conditions are nonroutine seasonal occurrences and are short in duration (a few hours to a day) (see Section 3.5.2).

6.2.1.8.12 Potentially adverse conditions

The potentially adverse conditions associated with the siting guideline for radioactive waste transportation are stated as follows:

"(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

"(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.

"(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

"(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options."

None of these potentially adverse conditions are present for transportation of radioactive waste to the reference repository location. Each of the potentially adverse conditions is addressed briefly. The first three potentially adverse conditions are generally antithetical statements of the related favorable conditions addressed earlier.

Potentially adverse conditions (1) and (2) address the costs, ease of construction, and potential hazards of truck and rail access routes. These access route characteristics were addressed in the statements concerning favorable condition (1) (see Subsection 6.2.1.8.3). These potentially adverse conditions are not present at the reference repository location, since the needed access routes are short, inexpensive and easy to construct, and relatively free of terrain-related potential hazards.

Potentially adverse condition (3) pertains to the need for significant reconstruction or upgrading of existing local highways and railroads providing access to regional and national transportation systems. As indicated in the response to favorable condition (2) (see Subsection 6.2.1.8.4), the existing local highway and railroad routes appear adequate to handle the needs of the Tri-Cities area within the foreseeable future. The incremental transportation density attributable to a repository at the reference repository location is small in comparison to the current traffic and, by itself, would not justify significant improvements to the existing local highways and railroads.

Potentially Adverse Condition (4) is similar in scope to favorable condition (5) (see Subsection 6.2.1.8.7), in that they pertain to transportation-related costs, environmental impacts, and risks to the public health and safety. However, favorable condition (5) addresses the effect of repository location relative to potential waste sources (i.e., transportation distances); whereas, potentially adverse condition (4) addresses the possible effects of local conditions. The major local condition that could adversely impact transportation costs, environmental impacts, or risks would be a large distance from regional or national transportation networks to the reference repository site via local highways and railroads. The proposed repository site is sufficiently close to major interstate highways (within 185 kilometers (115 miles)) and railroad classification yards (within 128 kilometers (80 miles)) that regional and local transportation is a small fraction of total shipping distance. The local condition that could result in a locally high environmental impact or risk to public health and safety is a large exposed population, which can be expressed arithmetically as the cumulative product of shipping distance and population density. For the Hanford Site, the local highways and railroads providing access to regional or national transportation networks are reasonably short and pass through areas of low population density. Therefore, potentially adverse condition (4) is not considered to be a negative factor in assessing suitability of the reference repository location from a transportation standpoint.

6.2.1.8.13 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Factors that support this finding are listed below.

- Access routes to the reference repository location would not pass through or otherwise conflict with any component of the National Park System, National Wildlife Refuge System, National Wilderness Preservation System, National Wild and Scenic Rivers System, or any comparably significant State-protected resource (reference Section 960.5-2-5(d)(2) and (3) of the General Siting Guidelines (DOE, 1984a)).

- Access routes would have no undesirable features that would require unique design or construction methods or special features of transportation system components, including the transportation packaging.

- Risks to public health and safety of the proposed access routes would be acceptably low, since these routes are short and pass through areas without population.

- Environmental impacts are expected to be exceptably low, since the access routes are short and do not pass through protected resource areas.

- Projected risks, costs, and other impacts of waste transportation have been considered in repository siting, and transportation operations would be conducted in compliance with applicable regulations.

Specific uncertainties related to the above supporting factors are listed below.

- Designs of the repository and its associated access routes are preliminary.

- Future characteristics of the transportation system cannot be accurately forecast.

- Future shipping cask designs have not been developed.

- Specific future usage of specific transportation routes cannot be forecast.

- Transportation modal split (i.e., among truck, rail, and barge) cannot be accurately forecast at this time.

6.2.2 SYSTEM GUIDELINES

"The guidelines in this Subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance before closure. The preclosure guidelines are separated into three system guidelines and eleven technical guidelines."

6.2.2.1 Preclosure radiological safety (Section 960.5-1(a)(1))

6.2.2.1.1 Qualifying condition

"Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A (see Appendix II of this part)."

6.2.2.1.2 Evaluation process

This guideline requires that any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR 20 (NRC, 1985b), 10 CFR 60 (NRC, 1985a), and 40 CFR 191, Subpart A (EPA, 1985).

To establish that the site meets the system guidelines, it is necessary to perform preliminary analyses to evaluate radiological impacts associated with repository operations. These analyses would be restricted to site data and preliminary facility designs. As a consequence, the analyses would be considered preliminary and subject to change as data, including mitigating and preventive features, are added to the data base and the repository design. Nevertheless, it is possible to make a preliminary judgment about the ability of the site to meet the system guidelines.

The following technical guidelines are relevant to the evaluation of this guideline.

- Population density and distribution (see Subsection 6.2.1.2).
- Meteorology (see Subsection 6.2.1.4).
- Offsite installations and operations (see Subsection 6.2.1.5).

During preclosure repository operations, the principal potential radiological exposure pathway for members of the public is by atmospheric releases. Meteorological characteristics of the site affect the travel time, direction, and dispersion of radionuclides released from a repository during normal or abnormal operating conditions. Meteorological characteristics of the reference repository location and the Hanford Site with respect to applicable qualifying conditions are described in Section 3.4.3.

The repository would be designed to prevent or mitigate atmospheric releases of radioactivity. The quantity of radioactive releases during normal operations, or as a result of hypothetical accident conditions, would be dependent on the types of waste handled and processing operations performed at the repository. Receipt and handling of prepackaged waste would involve negligible releases under normal operating conditions. Receipt and packaging of spent fuel assemblies would involve minor releases of fission gases, similar in kind to those experienced in spent fuel handling and storage facilities at nuclear power reactors (Section 6.4.1).

The demography (see Subsection 6.2.1.2) of the area is a factor in estimating potential population doses from repository releases. Richland, Washington (population 33,578) is the nearest and most likely downwind population center to the reference repository location based on the prevailing winds (approximately 16 percent of the time) at the Hanford Meteorological Station (see Subsection 6.2.1.4.4 and Fig. 3-37 and 3-41).

Site ownership and control are important from the standpoint of restricting access to areas that could place members of the public at risk. The reference repository location and surrounding Hanford Site are under the control of the U.S. Department of Energy, which restricts public access.

Compliance of the repository with radiological exposure criteria set forth in 40 CFR 191, Subpart A (EPA, 1985) will be judged along with contributing releases from other nearby commercial nuclear installations. Total estimated maximum exposure to an individual in the Hanford Site vicinity from all current and projected releases from commercial and defense nuclear installations and repository operations is approximately 2.8 millirems per year (see Subsection 6.2.1.5.2). The releases from a repository, in addition to the contributing releases from other facilities, would represent a small fraction of the allowable 25-millirem annual individual exposure.

6.2.2.1.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for preclosure radiological exposures cannot be made based on available data. The evidence regarding preclosure radiological exposures does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). Factors that support this finding are summarized below.

- The nearest highly populated area is Sunnyside, Washington, meters (15 miles) from the reference repository location. The nearest and most likely downwind population center to the reference repository location is Richland, Washington, 35 kilometers (22 miles) based on the prevailing winds at the Hanford Meteorological Station. There is no permanent population on the reference repository location. Due to the low population density of the surrounding area and the distance from the proposed repository site to highly populated areas, routine repository operations would not be expected to result in radiological exposure of the general public above applicable requirements.

- The meteorological conditions indicate that repository operations would not result in doses to the general public above allowable limits (see Subsection 6.2.1.4).

- The repository is designed to prevent or mitigate atmospheric releases of radioactivity. Repository emissions, under routine operating conditions, are not expected to exceed emission standards (Subsection 6.4.1.4.2).

- The doses from operations to individuals in the vicinity of the Hanford Site are greater than projected doses from repository operations. These doses are monitored and are within applicable federal standards (see Subsection 3.4.2.7.5).

Some uncertainties are associated with these factors and are summarized below.

- The dose calculations are based on a conceptual repository design.

- The quantity of radioactive releases during normal operations or resulting from hypothetical accident conditions would be highly dependent on the types of waste-handling and -processing operations performed at the repository.

6.2.2.2 Environment, socioeconomics, and transportation (Section 960.5-1(a)(2))

6.2.2.2.1 Qualifying condition

"During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste."

6.2.2.2.2 Evaluation process

Of the three preclosure system guidelines, the guideline on environment, socioeconomics, and transportation is ranked second in importance after preclosure radiological safety. The pertinent system elements consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services, (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by the repository, (3) the transportation infrastructures, and (4) the potential mitigating measures that could be used to achieve compliance with this guideline.

To establish that the reference repository location meets the system guideline and the associated technical guidelines, it is necessary to evaluate the potential impacts of the repository on the quality of the environment, social and economic conditions, and transportation systems. However, the evaluations of such impacts have inherent uncertainties, especially when the project is years from implementation. Furthermore, because only conceptual designs of the repository are available, this evaluation must be preliminary and include many assumptions. Finally, evaluations require site-specific data, which will be collected during the site investigations performed concurrently with site characterization if the site were selected for characterization. The qualitative evaluations presented earlier for the technical guidelines provide the basis to make a judgment that the site will comply with this system guideline.

The following technical guidelines are relevant to the evaluation of this system guideline.

- Environmental quality (see Subsection 6.2.1.6).
- Socioeconomic impacts (see Subsection 6.2.1.7).
- Transportation (see Subsection 6.2.1.8).

6.2.2.2.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for environment, socioeconomics, and transportation cannot be made based on available data. The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition on environment, socioeconomics, and transportation (Level 3). Factors that support this finding are summarized below.

- The environmental analyses conducted for the U.S. Department of Energy nuclear activities suggest that compliance with environmental laws and regulatory requirements would not be a significant problem if a repository were located at the reference repository location.

- The reference repository location is not within the boundaries of a nationally protected natural resource.

- The construction and operation of a repository would not be inconsistent with current and planned land use.
- No adverse environmental impacts on the quality of the environment have been identified that cannot be mitigated.
- No federally recognized threatened or endangered animal species are known to nest on or use the reference repository location as critical habitat.
- No federally recognized threatened or endangered plant species are known to exist on the reference repository location.
- There are areas of significant Native American resources on the Hanford Site; however, the distance from the repository to these resources indicates there would be no significant adverse impacts.
- Significant Federal- or State-protected resources do not exist at or near the reference repository location; hence, no conflicts exist.
- Projected employment and population growth caused by repository activities could be readily assimilated by the area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress on the community services and facilities.
- Projected employment, business, and community opportunities would strengthen the local community.
- A technically qualified work force (except for miners) is located nearby in the Tri-Cities and the surrounding areas.
- Growth in the primary sectors of employment is expected to continue in the future without disruption due to repository-related needs.
- Availability of water supply is not expected to be a problem for the reference repository location.
- Access routes to the reference repository location would not pass through or otherwise conflict with any component of the National Park System, National Wildlife Refuge System, National Wilderness Preservation System, National Wild and Scenic Rivers System, or any comparably significant State-protected resource (reference Section 960.5-2-5(d)(2) and (3) of the General Siting Guidelines (DOE, 1984a)).
- Access routes would have no undesirable features that would require unique design or construction methods or special features of transportation system components, including the transportation packaging.

- Risks to public health and safety of the proposed access routes would be acceptably low, since these routes are short and pass through areas without population.

- Environmental impacts are expected to be exceptably low, since the access routes are short and do not pass through protected resource areas.

- Projected risks, costs, and other impacts of waste transportation have been considered in repository siting, and transportation operations would be conducted in compliance with applicable regulations.

Uncertainties that are associated with the above factors are listed below.

- Impact projections were based on a repository design in the conceptual stage.

- Detailed information on the size and composition of the needed work force, especially during repository construction, is not available.

- Future characteristics of the transportation system cannot be accurately forecast.

- Transportation modal split (i.e., among truck, rail, and barge) cannot be accurately forecast at this time.

Another factor related to this discussion is that transportation costs and risks for the most distant site (the reference repository location) are greater than those of the sites nearer the projected waste sources. The life-cycle transportation cost for the reference repository location is small in comparison to an estimated repository life-cycle cost of roughly 12 billion dollars.

6.2.3 CONCLUSION REGARDING THE SUITABILITY OF THE SITE FOR DEVELOPMENT AS A REPOSITORY

On the basis of the findings stated in the preceding discussions of individual guidelines and made in accordance with Appendix III of the General Siting Guidelines (DOE, 1984a), it is concluded that the evidence does not support a finding that the reference repository location is disqualified, and does not support a finding that the reference repository location is not likely to meet the qualifying condition.

6.3 SUITABILITY OF THE SITE FOR SITE CHARACTERIZATION: EVALUATION AGAINST THE GUIDELINES THAT DO REQUIRE SITE CHARACTERIZATION

This section addresses guidelines that require site characterization. Where site characterization is required, the conclusions are preliminary and are based on evaluations that lack substantial site-specific subsurface data. Final conclusions cannot be made until necessary site-characterization activities are completed.

6.3.1 POSTCLOSURE TECHNICAL GUIDELINES (Section 960.4-2)

6.3.1.1 Geohydrology (Section 960.4-2-1)

6.3.1.1.1 Qualifying condition

"The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology."

6.3.1.1.2 Evaluation process

The process of evaluating the above qualifying condition entails an assessment of geologic, hydrologic, and geochemical information involving field and laboratory measurements, interpretive judgment, and numerical simulation techniques. These activities are accomplished by separate technical groups assigned to field study, data analysis, performance assessment, as well as integration across disciplines using systems engineering. Owing to the interdisciplinary nature of geohydrologic investigations, close interaction among these investigative components is maintained. At the same time, the U.S. Department of Energy is fostering internal and external peer reviews, as well as formal opportunities for technical and programmatic interactions, with the U.S. Nuclear Regulatory Commission and other involved or affected Federal, State, Indian, and public agencies.

Field studies involve a program of hydrologic measurements that include transmissivity, storativity, effective thickness, hydraulic diffusivity, hydraulic head, and dispersivity, as well as interpreted parameters (e.g., hydraulic conductivity, effective porosity, barometric and tidal efficiencies). The primary method of data acquisition involves transient stress testing of aquifers and water-level measurements via surface-based boreholes. Plans call for such testing to be carried out at various scales (see Subsection 4.1.1.3). A detailed, site-specific characterization of the Cohassett flow is planned using underground exploratory shafts and drifts. Additional field evaluation involves the chemical assessment of surface-water and ground-water samples.

Further data reduction, interpretation, and evaluation against other collateral data are carried out to formulate initially one or more conceptual models of the geohydrologic system. This activity allows investigations to identify alternative models from which to form a consensus on parameters used in the performance evaluation. Information assimilated at this level includes definition of principal hydrostratigraphic units, delineation of their associated potentiometric surface configurations and physical geometries, identification of rechange and discharge mechanisms and rates, delineation of hydraulic property values and their spatial distributions, evaluation of time-variant properties of the system under natural and artificial stresses, and use of alternative data sources (e.g., hydrochemical and isotopic data) to develop corroborative lines of evidence in support of an evolving conceptual understanding of the hydrologic system. One of the critical geologic inputs to developing this conceptual model is an understanding of the past and expected hydrologic impacts of a slowly changing geomorphic and tectonic setting.

Conceptual models serve as the physical basis for numerical simulations of the system performance; these numerical simulations represent the primary tools for predicting ground-water travel times and radionuclide transport under expected and reasonable scenario conditions. In the course of conducting field studies, data analyses, and performance assessments, a developing awareness of the level of uncertainty and additional information needs serve to guide future data acquisition.

6.3.1.1.3 Favorable condition

"(1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years."

Available data and current understanding of the ground-water system indicate that the reference repository location is likely to meet this favorable condition. This favorable condition appears present, because analyses of pre-waste-emplacement ground-water travel times to the accessible environment along pathways of likely radionuclide travel presented in Subsection 6.4.2.6.1 and in Clifton (1986) indicate there is a high likelihood that ground-water travel time will exceed 10,000 years.

Over the past few years, a number of preliminary, independently conducted modeling studies (Table 6-4) have evaluated potential ground-water flow paths and travel times. Studies listed in Table 6-4 indicate a broad range of travel times reflecting different conceptual models of the ground-water flow regime beneath the Hanford Site and different data bases used by each investigator. Results of these studies are included for completeness, but were not used as a basis for determining findings on this favorable condition and the disqualifying condition in Subsection 6.3.1.1.11.

Based on the current conceptual understanding of the geohydrologic system of the reference repository location and on the current data base for physical and hydraulic properties, a suite of pre-waste-emplacement ground-water travel-time models has been developed in support of this environmental assessment (Clifton, 1986). These models explicitly estimate the uncertainty in the predicted travel times. Subsection 6.4.2.6.1 discusses the inputs to and results of one of these travel-time models. This model accounts for three-dimensional ground-water flow in the layered basalt sequence above the Cohassett flow interior (Long and WWC, 1984). The results presented in Subsection 6.4.2.6.1 form the basis for the findings of this favorable condition and the travel-time disqualifying condition in Subsection 6.3.1.1.11.

The stochastic approach taken in Section 6.4.2.6.1 to evaluate ground-water travel time produces a distribution of possible travel times. The distribution results from natural variability and uncertainty in the hydrologic parameters. Conservative assumptions built into the flow model serve to shift the distribution to lower travel times. The upper and lower limits of the distribution are characteristic of unlikely paths of radionuclide travel and are, therefore, inappropriate for evaluating the favorable condition. The U.S. Department of Energy considers this judgment to be consistent with the U.S. Nuclear Regulatory Commission staff position (Browning, 1985) regarding the ground-water travel-time requirements in 10 CFR 60 (NRC, 1985a).

At this stage, the selection of an absolute limit at which the favorable condition is met is not warranted. The data base resulting from site characterization will permit better parameter estimation with less uncertainty and a more realistic construction of the model. These improvements are expected to narrow the range of travel times sufficiently to enable the specification of a limit.

For the interim, the mean of the modeling results is a mathematical approximation of the expected travel time (Davenport, 1970). The median is also a measure of central tendency and is a more conservative value. For this reason, median travel-time values, as well as mean values, are used in evaluating this guideline condition. In each set of conservative calculations of ground-water travel time (Section 6.4.2.6.1), the mean and median travel times exceed 10,000 years. Therefore, for purposes of this evaluation, the evidence indicates the favorable condition is present.

The principal results of the analyses in Subsection 6.4.2.6.1 indicate there is a probability of between 0.78 and 0.81 that pre-waste-emplacement ground-water travel time to the accessible environment will exceed

Table 6-4. Summary of ground-water travel-time estimates from modeling studies

Study	Purpose of study	Ground-water travel-time distance and (or) direction	Ground-water travel time
Los Alamos Technical Associates, Inc. (LATA, 1981)	Initial estimates of ground-water movement from hypothetical repository	Northward, 12 km (7.5 mi) to the Columbia River	33,000 yr
Pacific Northwest Laboratory (Dove et al., 1981)	Demonstration of numerical modeling capability	Northward, 12 to 16 km (7.5 to 10 mi) to the Columbia River	13,000 to 17,000 yr
Rockwell Hanford Operations (Arnett et al., 1981)	Estimate ground-water travel times from reference repository location	Southwest, 32 km (20 mi) to beneath the Columbia River	30,000 yr
U.S. Nuclear Regulatory Commission (NRC, 1983b)	Sensitivity of ground-water travel times to variation of model inputs	10 km (6.2 mi) from hypothetical repository	20 yr to greater than 40,000 yr
Rockwell Hanford Operations (Clifton et al., 1983)	Stochastic analysis of ground-water travel times	10 km (6.2 mi) within flow top of host rock	Median ground-water travel time of 17,000 yr
Rockwell Hanford Operations (Clifton et al., 1984)	Stochastic analysis of ground-water travel times for draft environmental assessment	10 km (6.2 mi) within flow top of host rock	Median ground-water travel times of 17,000, 81,000, and 86,000 yr
Rockwell Hanford Operations (Arnett and Sagar, 1984)	Evaluation of deterministic approaches for ground-water travel-time calculations using a preliminary measured effective thickness value	10 km (6.2 mi) within flow top of host rock	3,600 to 142,000 yr

10,000 years. Mean travel times range between 22,000 and 940,000 years, and median travel times range between 22,000 and 73,000 years. Although this estimate of exceedance probability is preliminary, it is considered reasonable and conservative for the following reasons.

- The travel time through the Cohassett flow interior is not included in the analysis that produced the above result. If ground-water travel time through the upper 10 meters (32 feet) of the Cohassett flow interior is accounted for, the exceedance probability for a 10,000-year travel time increases to at least 0.97 if the flow interior is not crossed by significant vertically oriented conduits for ground-water flow. Based on geologic and geophysical data, the dense portion of the Cohassett flow interior in the reference repository location contains primary cooling joints and possibly small-scale faults and shear zones. These features are expected to have low measured hydraulic conductivities due to secondary minerals that have filled joints and fractures, and high in situ stresses that maintain a closed joint and fracture system (see Section 3.3.2).

- The analyses presented in Subsection 6.4.2.6.1 and in Clifton (1986) make use of available transmissivity data from Grande Ronde Basalt flow tops in and around the Cold Creek syncline. Some of these transmissivities are in areas distant from the reference repository location and vicinity. These transmissivities tend to be larger, on the average, than the transmissivities of Grande Ronde Basalt flow tops within the reference repository location. The apparent increase in Grande Ronde Basalt flow-top transmissivity moving away from the reference repository location may be related to an observed thickening of flow-top breccia in the same direction. The effect of excluding the transmissivities that are distant from the reference repository location would increase the predicted travel times (Clifton, 1986). Therefore, these distant values were retained within the data set used to make ground-water travel-time predictions.

- The sensitivity of predicted travel times to some critical model-specific inputs (e.g., head gradient and effective porosity) has been examined. The input values used in the analyses are expected to underestimate ground-water travel time.

It is emphasized that ground-water travel-time estimates in Subsection 6.4.2.6.1 and Clifton (1986) are preliminary. Changes are expected in future predictions of ground-water travel times as data are collected and the conceptual model of the ground-water flow regime is refined, if site characterization proceeds. The combination of existing information and planned data-gathering activities discussed in Subsection 6.3.1.1.11 and in Section 4.1 have a good likelihood of quantifying pre-waste-emplacement ground-water travel times with the confidence needed for the licensing process. Geohydrologic studies have progressed to the point where various concepts about the ground-water flow regime beneath the Hanford Site have been identified (Gephart et al., 1983). Experiments are quantifying uncertainties in the data base, and new boreholes are planned or have been constructed. The additional data resulting from this work would be integrated into performance assessment studies for future estimates of ground-water travel times.

6.3.1.1.4 Favorable condition

"(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years."

The current estimation of the rate, probability of occurrence, and projected impact of identified major hydrologic processes on waste isolation support a finding that the reference repository location is likely to meet this favorable condition. This favorable condition appears to be present, because the hydrologic processes that operated during the Quaternary Period had mostly transient, local, and shallow effects on the hydrologic systems. These processes are expected to continue for the next 100,000 years and, therefore, they should not affect the ability of a deep geologic repository to isolate waste.

The period addressed under this favorable condition extends from approximately 1.8 million years before present (beginning of the Quaternary Period) to 100,000 years into the future. Examples of geologic processes that may impact the ground-water flow system during such a period are out-lined in Table 6-5. The likelihood of occurrence and hydrologic effects of these processes is not quantified. However, the climate of the Hanford Site region (Subsections 6.3.1.4.2 and 6.3.1.4.3) has been arid or semiarid for at least the past 3 million years. This condition is expected to remain essentially unchanged over the next 100,000 years, except for a postulated colder, drier climate associated with a glacial advance. Therefore, during the next 100,000 years, prevailing surface and ground-water conditions and dynamics are not expected to be significantly altered. Any potential hydrologic impacts are expected to be mostly transient, localized, and (or) shallow phenomena that would not significantly change the waste-isolation potential of the deep basalt environment in the reference repository location. If deep hydraulic head or hydraulic property changes should occur, the projected retardation characteristics of radionuclides in a basalt environment and conservatism already integrated into performance assessment predictions (Section 6.4.2) are not expected to result in an adverse impact or change in the ability of the repository and host rock to isolate waste over the next 100,000 years.

Table 6-5. Potential geologic or climatologic processes and their hydrologic effects

Geologic or climatologic process*	Possible hydrologic effect
Glaciation	
Pluvial climate established	Alteration of recharge and (or) discharge rates and areas
Surface drainage changes	Changes in hydraulic heads and gradients
Stress loading	Near-surface lowering of rock permeability due to ice loading
Tectonics	
Activation of new or reactivation of old tectonic zones	Creation of new ground-water-flow paths or blockage of existing paths
Microearthquakes	Local alteration of hydraulic head patterns and gradients
	Local changes in hydrologic property distributions
	Flow system(s) interconnection or blockage
Volcanism	
Renewed Columbia River Basalt Group volcanism	Alteration of stream drainages
Dike generation	Confinement of existing unconfined aquifer
Volcanic mudflows (lahars)	Local redistribution of hydraulic heads
Geothermal activity	Flow system(s) interconnection or blockage

*Any process or combination of processes could result in one or more of the possible hydrologic effects.

6.3.1.1.5 Favorable condition

"(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty."

Available data and current understanding of the geohydrologic system support a finding that the reference repository location is not likely to meet this favorable condition. This favorable condition does not appear to be present, because the reference repository location and surrounding geohydrologic system are not expected to be easily (readily) characterized and modeled. A program has been developed and is being implemented to investigate the reference repository location with the confidence needed for addressing repository licensing issues.

This favorable condition contains a phrase that should be interpreted before a response is given. The phrase is ". . . can be readily characterized and modeled with reasonable certainty." First, "can be" is interpreted in the future sense; that is to say, based on present knowledge is there a reasonable expectation that the geohydrologic system can be readily (that is, easily) characterized and modeled as a result of site characterization? Second, ". . . readily characterized and modeled with reasonable certainty" is interpreted to mean that the geohydrologic system can be characterized and modeled with the confidence required for repository licensing using reasonably available investigative technology.

The basic stratigraphic, structural, and tectonic setting of the Hanford Site is discussed in summary reports (e.g., Myers, Price et al., 1979; Myers and Price, 1981; DOE, 1982e; Caggiano and Duncan, 1983; and Long and WCC, 1984). Such information has enabled geologists to establish many fundamental regional and site-specific aspects of the stratigraphic, structural, and tectonic setting of the reference repository location. As addressed in a U.S. Department of Energy report (DOE, 1982e) and in this environmental assessment, uncertainties regarding the geologic setting remain. Site-investigation activities are under way to answer questions essential for satisfying licensing requirements.

Knowledge of the subsurface hydrology of the reference repository location and vicinity is less advanced than the knowledge of geology. As addressed in Section 3.3.2, reconnaissance testing has resulted in preliminary estimates of hydraulic properties of basalt flow tops, flow interiors, and sedimentary interbeds, as well as having identified broad hydraulic head distributions. In addition, a range of reasonable conceptual ground-water flow models has been developed. Because of the preliminary nature of available hydrologic information, a large uncertainty is associated with these data. For this reason, several data-gathering activities have been completed and planned, such as the installation of additional piezometers, large-scale pump (stress) tests, more tracer testing, and an exploratory shaft program (see Section 4.1). These studies are being planned and (or) carried out in consultation with such organizations as the U.S. Geological Survey and U.S. Nuclear Regulatory

Commission. For example, the basic piezometer layout and large-scale pump test approach for investigating the reference repository location was agreed on between the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission (DOE/NRC, 1983). Although the specifics of this understanding will change as data are collected, the principals involved believe that the investigative approach recommended is acceptable for developing the geohydrologic data base needed for addressing site-characterization issues.

In a U.S. Nuclear Regulatory Commission draft technical position paper (NRC, 1983a, p. 12), it is stated:

> "This site technical position provides a broad summary of an approach that the NRC staff would find acceptable for developing and then evaluating the hydrogeologic investigation program at the BWIP site. The proposed approach takes advantage of the existing facilities and previous experience at Hanford, including the geological characterization of the site and the existence of boreholes open in the Grande Ronde Formation. In addition, the physical installations needed to implement this program also could be used in testing to obtain the data needed to address the areas of solute transport, long-term measurements of hydraulic head, and hydrochemistry."

While characterization is not expected to be easy in any geologic medium, a basalt environment does have several potentially favorable attributes, including the following:

- The site-characterization approach is designed to reduce uncertainty concerning areal hydraulic properties within the reference repository location and will rely primarily on hydraulic stress tests. This approach has been reviewed and is supported by the U.S. Nuclear Regulatory Commission. For example, the U.S. Nuclear Regulatory Commission states in their draft technical position paper (NRC, 1983a, p. 4):

  > "The basic approach of this site technical position is that the hydrogeologic characterization of the Hanford Site should rely to the maximum extent possible on direct testing of the hydraulic response of the site to an induced hydraulic stress."

- The hydraulic testing of layered intraflow features (e.g., flow tops and interbeds) offers an opportunity to examine the continuous versus discontinuous hydraulic nature of basalt stratigraphy. This is important knowledge when addressing questions on the possibility of previously undetected structures and on assigning model boundaries for ground-water travel-time and solute-transport calculations.

- The existence of conductivity contrasts between basalt flow interiors, and flow tops (see Section 3.3.2) offers the possibility of quantifying leakage across flow interiors. This is done by pump testing within flow tops and monitoring water-level responses within flow interiors and overlying and underlying flow tops or interbeds (see Subsection 4.1.1.3).

The water-level data collected from three new piezometer suites (Jackson et al., 1984) installed in and near the reference repository location generally support earlier concepts of hydraulic head distributions in the area. For example, earlier concepts of hydraulic head distributions in the reference repository location are summarized in a report by the of U.S. Department of Energy (DOE, 1982e, Table 5-50), which includes expected vertical head distributions for the Saddle Mountains, Wanapum, and Grande Ronde Basalts. Based on hydraulic heads measured during the reconnaissance drill-and-test program, heads were projected to decrease with depth through the Saddle Mountains Basalt, change little in Wanapum Basalt, and be uniform to increasing with depth in Grande Ronde Basalt. Head measurements (Yeatman and Bryce, 1984a, 1984b; Bryce and Yeatman, 1985) subsequently taken in the three piezometer suites within and adjacent to the reference repository location confirmed these predictions. This provides increased confidence that the reference repository location can be characterized using available investigative technology.

Site-characterization data are expected to refine the conceptual understanding of the hydrologic setting as needed to address quantitatively, with reasonable confidence, critical licensing questions regarding past, present, and expected behavior of the ground-water system.

6.3.1.1.6 Favorable condition

"(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:

"(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.

"(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.

"(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

"(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment."

Information suggests that the third subcondition of this favorable condition is present, and the other subconditions are not present at the reference repository location. Therefore, this favorable condition is present based on a low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

Data for addressing favorable condition 4(i) suggest that the hydraulic conductivity of basalt flow interiors is low (see Subsection 3.3.2.1). (Hydraulic conductivities on the order of 10^{-8} to 10^{-9} meter per second (10^{-3} to 10^{-4} foot per day) are interpreted as the upper bound for low hydraulic conductivity. These are values typical of marine clays and unfractured metamorphic rocks, and represent that portion of the range of hydraulic conductivity where fluid movement by diffusion versus advection begins to dominate.) Basalt flow tops and sedimentary interbeds separating flow interiors normally have hydraulic conductivities greater than those in flow interiors. Thus, the geohydrologic system consists of alternating rock layers having low to high conductivities. The deep basalts appear to meet the first part of this favorable condition regarding a host rock of low hydraulic conductivity. However, basalt does not appear to meet the second half of the condition (i.e., low conductivity for surrounding geohydrologic units). Information needed to address this favorable characteristic fully is discussed in Section 4.1.

Within basaltic rocks, ground-water occurrence and movement are mostly within flow tops and interbeds that are permeable, as discussed in Sections 2.1.4 and 3.3.2. The basalt flow interiors separating individual flow tops and interbeds appear to act as semiconfining, low conductivity aquitards through which some (yet unquantified) vertical leakage occurs along cooling fractures and (or) structural discontinuities. As noted in the above-referenced sections, the concept of lateral ground-water movement along flow contacts and (or) interbeds and low flow-interior conductivities has been suggested by several field investigations (e.g., LaSala et al., 1973; Newcomb, 1965; Luzier and Burt, 1974; DOE, 1982e). Field studies addressing the quantification of vertical leakage across basalt flow interiors are discussed in Section 4.1.

Ground water moving from the vicinity of a repository would travel through fractures in the Cohassett flow interior before reaching basalt flow tops or bedrock structural discontinuities. Lying between the repository and land surface are some 20 separate basalt flows having flow interiors of low hydraulic conductivity and flow tops and (or) interbeds possessing a wide range of conductivity values.

Seventeen hydrologic tests have been conducted across the dense entablature and colonnade portions of individual flow interiors at depths from approximately 360 to 1,200 meters (1,200 to 3,900 feet) beneath the Hanford Site. Horizontal hydraulic conductivities measured ranged from 10^{-10} to 10^{-16} meter per second (10^{-5} to 10^{-11} foot per day) with a median of 10^{-13} meter per second (10^{-8} foot per day). (The lower limit of detection is considered to be approximately 10^{-13} to

10^{-14} meter per second (10^{-8} to 10^{-9} foot per day)). Low hydraulic conductivities for flow interiors have also been reported or suggested by other investigators within the Hanford Site and Columbia Plateau (e.g., LaSala and Doty, 1971; Newcomb, 1982). Field tests quantifying vertical conductivities and evaluating test methodologies within flow interiors are in progress. An initial ratio-type test conducted by Spane et al. (1983) suggests a vertical hydraulic conductivity of approximately 10^{-10} meter per second (10^{-5} foot per day) for a test zone in the Rocky Coulee flow interior (see Subsection 3.3.2.1.1). As discussed in Subsection 4.1.1.3, measurements of the vertical hydraulic conductivity of flow interiors are a central activity in the planned large-scale pump test and the exploratory shaft program.

Tanaka et al. (1974) performed a digital model study of the ground-water hydrology in the Columbia Basin Irrigation Project area. This was a cooperative study between the State of Washington Department of Ecology and the U.S. Geological Survey. One data need was for vertical hydraulic conductivity. On pages 23 and 24 of Tanaka et al. (1974), it is stated:

> "In the absence of reliable field data on the vertical hydraulic conductivity of basalt in the project area, several hydraulic conductivity values were estimated indirectly by analysis of the head response in basalt to application of known amounts of irrigation water, and these values were tested as model parameters. After repeated trials on the model, comparing different values of hydraulic conductivities to head response in the upper and lower aquifers, an average value of 0.00002 foot per day (within a range of 0.000001 foot/day to 0.000037 foot/day) gave computed heads that were similar in response to measured heads in both aquifiers."

In metric units, the above range equates to 3×10^{-12} to 1×10^{-10} meter per second. In MacNish and Barker (1976, p. 5), vertical hydraulic conductivity was said to be "as small as 0.00000005 ft/s." This is equivalent to 1×10^{-8} meter per second. (This computer model-generated value for hydraulic conductivity is approximately two orders of magnitude larger than that suggested by available field test data for basalt flow interiors.) The representativeness of the above estimates for vertical hydraulic conductivity will be examined during large-scale pump tests and research conducted from within the exploratory shaft facility.

Field-derived values of the anisotropy ratio of vertical to horizontal hydraulic conductivity within basalt flow interiors are not available. Estimates based on ground-water model simulations and statistical analysis of fracture data are reported to range between 3.5 to 1 and 10 to 1 (DOE, 1982e). Thus, once several field measurements become available, it is believed the vertical hydraulic conductivity of undeformed flow interiors will likely be within a factor of approximately 10 of horizontal conductivity values currently reported. The uncertainty of this concept is recognized and site-characterization research (see Subsection 4.1.1.3) will address this uncertainty.

After ground water travels through cooling fractures or other pathways within a basalt interior, it may enter a flow contact. Commonly, these contacts represent the nearest potential aquifer (i.e., high-transmissive rock layer) to a repository. In excess of 200 single-borehole hydrologic tests have been conducted in flow tops and interbeds in some 35 separate boreholes across the Hanford Site. These data indicate that, within the Saddle Mountains and Wanapum Basalts (see Fig. 3-6), the hydraulic conductivities of most individual flow tops and interbeds range between 10^{-4} and 10^{-7} meter per second (approximately 10^{1} and 10^{-2} foot per day) with a geometric mean of approximately 10^{-5} meter per second (10^{0} foot per day). Some hydraulic conductivity values as high as 10^{-2} to 10^{-3} meter per second (10^{3} to 10^{2} feet per day) and as low as 10^{-8} to 10^{-10} meter per second (10^{-3} to 10^{-5} foot per day) are reported for selected flow tops in the Saddle Mountains and Wanapum Basalts (Long and WCC, 1984). High hydraulic conductivity values are commonly associated with the Priest Rapids Member of the upper Wanapum Basalt. Most hydraulic conductivity values within Grande Ronde Basalt flow tops range between 10^{-5} and 10^{-9} meter per second (10^{0} and 10^{-4} foot per day) with a geometric mean of approximately 10^{-7} meter per second (10^{-2} foot per day) (Long and WCC, 1984). A few hydraulic conductivity values as high as 10^{-3} to 10^{-4} meter per second (10^{2} to 10^{1} feet per day) and as low as 10^{-10} to 10^{-11} meter per second (10^{-5} to 10^{-6} foot per day) are also reported (Long and WCC, 1984). The general uncertainties of these values are addressed in Subsection 3.3.2.1.

Hydraulic head data for addressing favorable condition 4(ii) in the Cold Creek syncline near the reference repository location indicate that the head gradient in the shallow basalt is downward, while that in the deeper basalt (where the host rock exists) is upward. Therefore, favorable condition 4(ii) is not present at the reference repository location. Section 3.3.2 provides a quantitative discussion of these gradients.

When piezometric data from shallow and deep basalts (as outlined in Section 3.3.2) are combined with hydraulic head information collected on a progressive drill-and-test basis (DOE, 1982e; Long and WCC, 1984; Strait and Mercer, 1984), a preliminary understanding appears to emerge of the broad head patterns that might exist across the Hanford Site. The western Hanford Site, that region closest to the Rattlesnake Hills and Yakima and Umtanum Ridges, appears to be a recharge area for the shallow basalts (see Fig. 3-4). There, hydraulic heads decrease with depth. A portion of this gradient might be attributed to artificial recharge from past water disposal on the Hanford Site. Eastward across the Hanford Site, heads become more uniform with depth in the central Cold Creek syncline. This suggests lateral ground-water movement. Close to the Columbia River, heads either increase with depth or have a variable pattern suggesting potential discharge. In deep basalts, hydraulic head data suggest an upward gradient within the Cold Creek syncline, which includes the area occupied by the reference repository location.

The above statements on hydraulic head patterns are not given as conclusions, but rather as conceptualizations based on information available to researchers at the time of their studies and on data uncertainties as noted in Section 3.3.2. The existing hydraulic head data for addressing favorable condition 4(iii) suggest that the lateral head gradient in geohydrologic units is low. Available lateral and vertical head data suggest that this favorable condition is met by the reference repository location, although additional studies are required to develop a final conclusion (see Section 4.1).

Table 6-6 shows a comparison of areal head gradients between two boreholes located inside and outside the reference repository location (Fig. 6-3). The rock intervals selected for head comparisons are within the Wanapum and Grande Ronde Basalts. The proposed repository is within the Grande Ronde Basalt; the Wanapum Basalt directly overlies this formation. Gradients given appear typical of other boreholes in the reference repository location compared to those farther southeast in the Cold Creek syncline. Some heads were collected during hydrologic reconnaissance studies when water levels were measured in new boreholes on a progressive drill-and-test sequence as the borehole was deepened over a period of several months. Heads measured using this technique are considered preliminary because of possible local head disturbances resulting from hole emplacement, hydrologic tests, and natural head changes over time. Baseline hydraulic heads for these same basalts are now being collected within and near the reference repository location in piezometers and across the Hanford Site in existing shallow and deep piezometers (e.g., Swanson and Leventhal, 1984; Swanson and Wilcox, 1985; Yeatman and Bryce, 1984a, 1984b; Bryce and Yeatman, 1985).

On an average, the areal hydraulic head gradient across the Cold Creek syncline, where the boreholes in Table 6-6 are located, appears to be low (approximately 1×10^{-4} meter per meter (1×10^{-4} foot per foot)). Within the reference repository location, areal head gradients monitored in boreholes DC-19, DC-20, and DC-22 range between 8×10^{-5} and 4×10^{-4} meter per meter (8×10^{-5} and 4×10^{-4} foot per foot) (see Section 3.3.2).

Relative to favorable condition 4(iv), the present conceptual understanding of ground-water movement from a repository involves vertical flow through a basalt interior of low hydraulic conductivity and then lateral flow within a flow top(s) of higher conductivity. Likely radionuclide pathways to the 5-kilometer (3-mile) accessible environment are expected to be along flow tops. Because rocks of higher hydraulic conductivity generally have a higher effective porosity (and vice versa), radionuclide movement is expected to take place in basalt layers having low and high effective porosities. Therefore, the fourth favorable characteristic is not met at the reference repository location.

Estimates of effective porosity are obtained from field tracer experiments such as described in Gelhar (1982) and Leonhart et al. (1982). To date, two tracer tests have been performed within a single

Table 6-6. Comparison of observed hydraulic head gradients for selected basalt flows in the Wanapum and Grande Ronde Basalts

Stratigraphic interval	Observed hydraulic heads (m above mean sea level)[a]		Average areal head gradient between boreholes (m/m)[b]
	Head in DC-22	Head in DC-15	
Wanapum Basalt			
Priest Rapids Member	122.1	117.5	1×10^{-4}
Sentinel Gap flow	122.2	118.0	1×10^{-4}
Ginkgo flows	122.3	117.5	1×10^{-4}
Grande Ronde Basalt			
Rocky Coulee flow	122.9	119.0	1×10^{-4}
Cohassett flow	123.1	119.0	1×10^{-4}
Umtanum flow	123.2	121.5	4×10^{-5}

NOTE: 1 meter = 3.28 feet.

[a]Observed hydraulic heads in borehole cluster DC-22 are monitored values recorded during March 1985. Values are reported to nearest 0.1 meter (Bryce and Yeatman, 1985). Observed hydraulic heads in borehole DC-15 were collected in 1980 on a drill-and-test basis. Values are reported to nearest 0.5 meter (Swanson and Wilcox, 1985).

[b]Boreholes DC-22 and DC-15 are separated by 37 kilometers (approximately 23 miles).

7 0 1 6 8 1 1 7 6 5

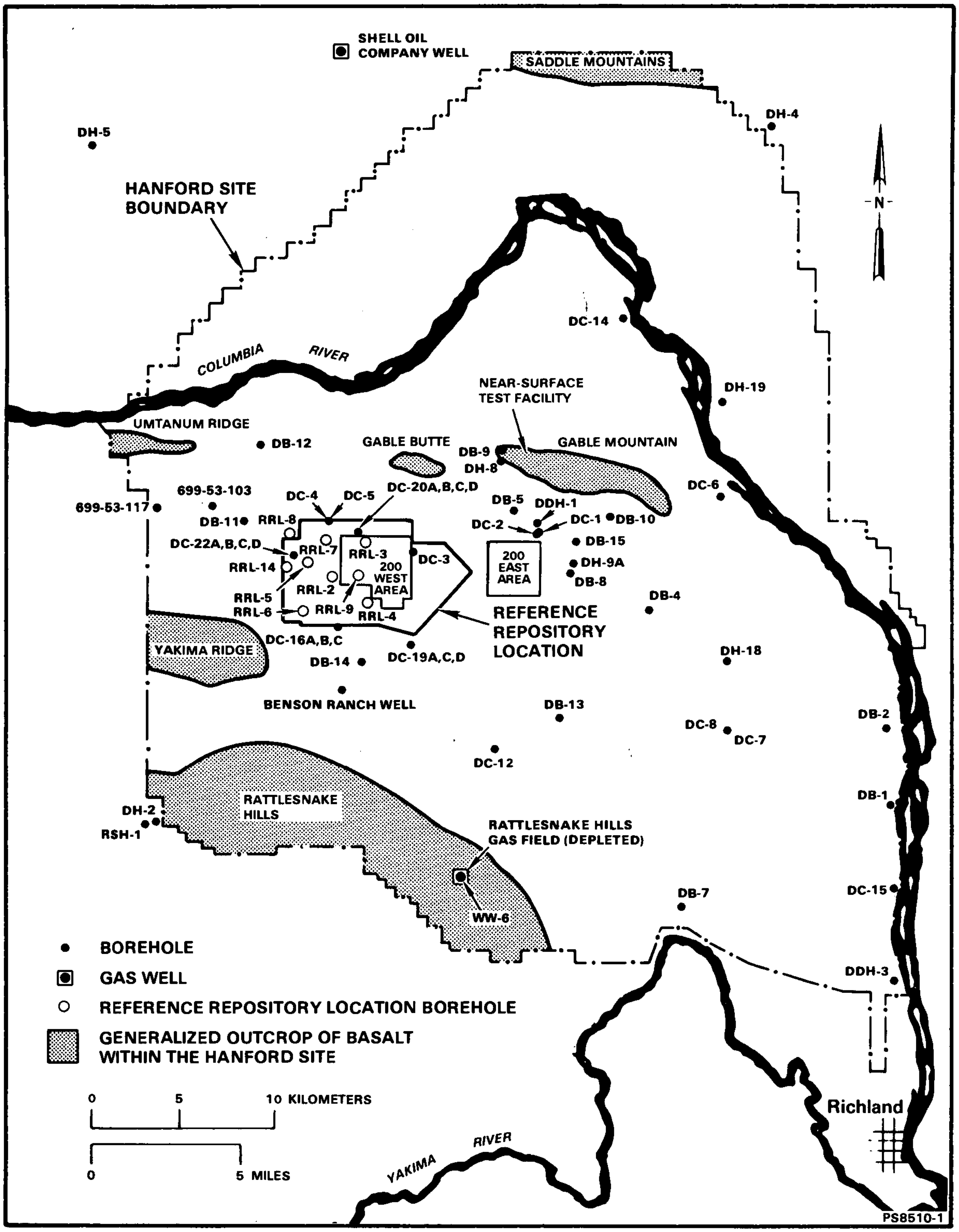


Figure 6-3. Location map for selected boreholes.

horizon within a Grande Ronde Basalt flow (the McCoy Canyon flow top). Estimates for the effective thickness of the test horizon ranged between approximately 2 x 10^{-3} to 3 x 10^{-3} meter (0.006 to 0.01 foot). Data suggest that the effective porosity of this flow top is between 1 and 0.01 percent. Additional tracer testing must be performed before the required understanding of effective porosities within flow tops and flow interiors is reached. Studies to collect these data are discussed in Subsection 4.1.1.3.

6.3.1.1.7 Favorable condition

"(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

"(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

"(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

"(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

"(iv) A host rock that provides for free drainage.

"(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration."

This favorable condition applies to an unsaturated zone. This condition does not apply to the reference repository location, since the Cohassett flow is located below the water table (i.e., in a water-saturated environment). Therefore, no evaluation of this guideline is required.

6.3.1.1.8 Potentially adverse condition

"(1) Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units--sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions."

This potentially adverse condition applies to naturally induced changes in pre-waste- versus post-waste-emplacement geohydrologic conditions. (Expected changes from human activities are addressed in Subsection 6.3.1.8.9 and thermal-induced changes from waste emplacement are covered in Subsection 6.3.3.2.8).

Current understanding of the ground-water system and performance assessment results do not support a finding that the reference repository location is likely to have this potentially adverse condition. This potentially adverse condition does not appear to be present, because ground-water travel times to the accessible environment (and associated radionuclide transport) under post-waste-emplacement conditions are not expected to be significantly different from pre-waste-emplacement travel times.

Relative to climatically induced changes to the geohydrologic system, the prevailing deep ground-water conditions are not expected to be significantly altered over the next 100,000 years (see Subsection 6.3.1.1.4). The Hanford Site area has been arid to semiarid for at least the last 3 million years (Subsection 6.3.1.4.3). This condition is expected to remain essentially unchanged over the next 100,000 years. Predicted periods of glaciation may cause formation of ice dams and surface flooding beginning in 35,000 years. However, the short duration of such floods is expected to minimize any impact on the deep ground-water system (Subsection 6.3.2.1.3). Thus, significant natural changes to the transport characteristics and hydrologic properties of the basalt system beneath the reference repository location are not expected.

Subsection 6.4.2.6.1 presents the results of pre-waste-emplacement ground-water travel-time analyses. No significant post-waste-emplacement changes to these travel times are expected. Since radionuclides travel in response to ground-water conditions and prevailing geochemical retardation factors, no significant increase in radionuclide transport is expected as a result of potential post-waste-emplacement changes in the geohydrologic environment.

6.3.1.1.9 Potentially adverse condition

"(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment."

The deep basalt ground waters existing along likely ground-water flow paths from the host rock to the accessible environment contain natural chemical constituents that would require removal or treatment before these waters would be suitable for human consumption and crop irrigation (these likely flow paths exist in the Grande Ronde and lower Wanapum Basalts). Therefore, this potentially adverse condition is not present at the reference repository location.

A portion of the total dissolved solids concentrations of basalt ground waters consists of fluoride. Within and adjacent to the reference repository location, fluoride concentrations within Grande Ronde Basalt ground water in typical boreholes (e.g., DC-16, RRL-2, and RRL-14) (see Fig. 6-3) range from 11 to 27 milligrams per liter (Early et al., 1985). Across the entire Hanford Site, fluoride concentrations of 11 to 44 milligrams per liter are measured in Grande Ronde Basalt ground water (see Table 3-15). This is the basalt formation where the feasibility of repository construction is being studied. Within the Priest Rapids and Roza Members of the upper Wanapum Basalt, fluoride contentrations of approximately 9 milligrams per liter are also reported for bore-holes DC-16, RRL-2, and RRL-14. Across the Frenchman Springs Member of the middle and lower Wanapum Basalt, fluoride concentrations range between 12 and 25 milligrams per liter (Early et al., 1985). Across the entire Hanford Site, fluoride concentrations of 0.4 to 27 milligrams per liter are measured in Wanapum Basalt ground water (see Table 3-15). The maximum fluoride concentrations for safe drinking water as established by the U.S. Environmental Protection Agency (EPA, 1976, p. 5) varies between approximately 1.4 and 2.4 parts per million, depending on sample temperature. (In November 1985, the U.S. Environmental Protection Agency published a final rule that established a Recommended Maximum Contaminant Level for fluoride in drinking water of 4 parts per million. Also in November 1985, a proposed rule by the U.S. Environmental Protection Agency was released that would raise the primary drinking water Maximum Contaminant Level to 4 parts per million and proposed a secondary Maximum Contaminant Level of 2 parts per million.) This regulatory limit is exceeded by all Grande Ronde Basalt ground waters sampled beneath the Hanford Site, as well as all Wanapum and Grande Ronde Basalt ground waters sampled within the Cold Creek syncline in which the reference repository location lies. Treatment of these ground waters would be necessary before human consumption.

A single lethal dose of fluoride is considered to be approximately 14 to 70 milligrams per kilogram of body weight in an adult human (Gosselin et al., 1977). A person weighing 70 kilograms (154 pounds) would have to consume between 50 and 250 liters (13 to 66 gallons) of water containing 20 milligrams per liter fluoride for a lethal dose. (Twenty milligrams per liter is an average Grande Ronde Basalt groundwater concentration.) Nausea can accompany ingestion of as low as 7 milligrams fluoride and acute vomiting can occur at consumption of fluoride levels approaching 29 milligrams (Leland et al., 1980). Therefore, an average adult would have to consume 0.35 liter (0.1 gallon) of water containing 20 milligrams per liter fluoride to become nauseated and 1.5 liter (0.4 gallon) of this same water to experience vomiting. Chronic endemic fluorosis due to high concentrations of natural fluoride in ground water is characterized by symptoms such as mottling of teeth, weakening of bones, and nervous disorders (Gosselin et al., 1977).

From the standpoint of crop irrigation, sodium and salinity concentrations in the Grande Ronde Basalt ground waters appear to be of concern. Irrigation waters of high sodium content (expressed as a sodium adsorption ratio) can cause soils to crust and swell, thus, decreasing permeability and contributing to drainage and salinity-control problems (Bohn et al., 1979). Waters are divided into four classes in respect to sodium hazard as expressed as a sodium adsorption ratio: Low, medium, high, and very high, depending on the electrical conductance of the water. At electrical conductivity values of 100 micromhos per centimeter, the dividing points between the above four classes are: 10, 18, and 26. With increasing salinity (e.g., at 2,250 micromhos per centimeter), the corresponding dividing points are approximately 4, 9, and 14 (Allison, 1964). The Grande Ronde Basalt ground waters beneath the Hanford Site fall within the very high range (i.e., sodium adsorption ratio values in the 30's and 40's) in the above salinity cases. At boreholes DC-16, RRL-2, and RRL-14 within and adjacent to the reference repository location (see Fig. 6-3), the sodium adsorption ratio for Grande Ronde Basalt ground water ranges between 36 and 70. Within the same three boreholes, a sodium adsorption ratio of 28 to 29 appears typical of the upper to middle Wanapum Basalt. This value increases to 43 in the lower Wanapum Basalt flows.

Total salt (salinity) concentration is one of the most important criterion to establish irrigation water quality. On the basis of electrical conductivity measurements, waters are divided into four classes: Low, medium, high, and very high salinity. The dividing points between classes are electrical conductivity values of 250, 750, and 2,250 micromhos per centimeter (Allison, 1964). The Grande Ronde Basalt ground waters within the Cold Creek syncline where the reference repository location lies have an electical conductivity of approximately 900 to 2,000 micromhos per centimeter and, thus, fall in the high salinity range.

Ground water within the Priest Rapids and Roza Members of the upper Wanapum Basalt have an electrical conductivity of 700 to 800 micromhos per centimeter. These values are measured from waters sampled in boreholes DC-16, RRL-2, and RRL-14 (see Fig. 6-3). Across the Frenchman Springs Member of the middle to lower Wanapum Basalt, ground water has an electrical conductivity of 1,200 to 1,700 micromhos per centimeter. Therefore, all Wanapum Basalt ground water within and adjacent to the reference repository location is classified in the high salinity range, according to Allison (1964).

Throughout the Columbia Plateau, ground water used for irrigation is of distinctly lower salinity than found in the Grande Ronde and lower Wanapum Basalts in the vicinity of the reference repository location. This is true of Wanapum and Grande Ronde Basalt ground water in the upper Cold Creek syncline, west of the hydrologic and geochemical anomaly occurring along the Cold Creek barrier (see Section 3.3.2). Sodium and chloride concentrations for waters from these two areas are plotted in Figure 6-4. Ground water in the Columbia Plateau, excluding the Hanford Site, is characterized by low chloride (generally 10 parts per million or less) and sodium concentrations ranging from near zero to slightly greater than 100 parts per million (U.S. Geological Survey WATSTOR data base). The shallow, confined ground waters in the Saddle Mountains at the Hanford Site have similar characteristics. Water with these characteristics is

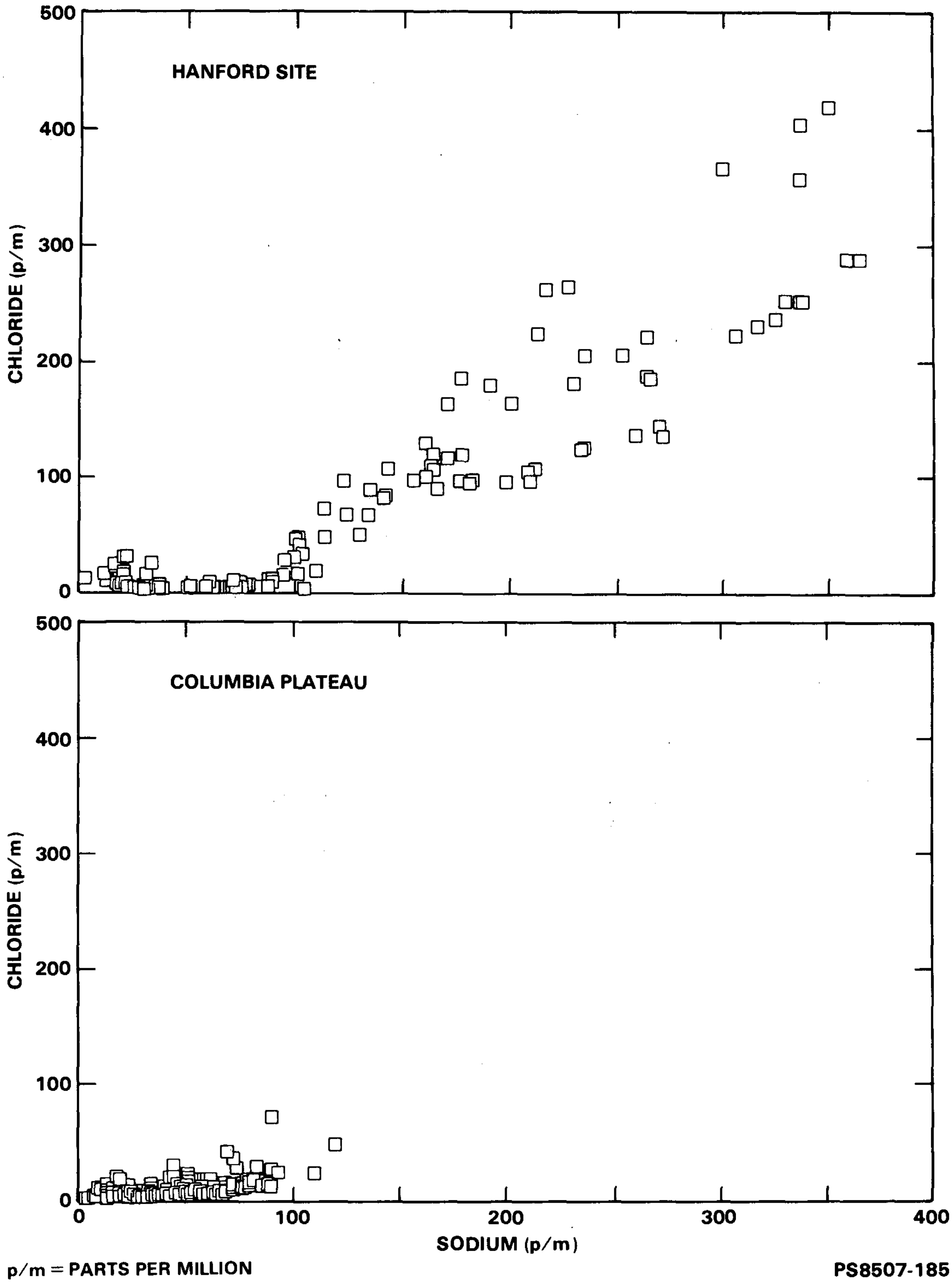


Figure 6-4. Sodium and chloride concentrations for the Hanford Site and Columbia Plateau.

found at all depths in the plateau where data are available. There appears to be no increase in salinity with depth in the Columbia Plateau, although irrigation water is pumped from Grande Ronde and Wanapum Basalts. These basalts are at shallower depths in the plateau outside of the Hanford Site. However, at the Hanford Site, ground-water salinity increases with depth in the Wanapum Basalt and reaches a maximum in the Grande Ronde Basalt, where salinity is uniformly high with most specific conductivities between approximately 1,500 and 2,000 micromhos per centimeter and sodium and chloride concentrations on the order of 350 and 450 parts per million, respectively (Early et al., 1985). Therefore, deep ground water in the vicinity of the reference repository location is distinct from irrigation waters used elsewhere in the Columbia Plateau even though they are located in the same stratigraphic horizons.

The type of saline ground water found in the Wanapum and Grande Ronde Basalts at the Hanford Site is not used for irrigation elsewhere in the Columbia Plateau. This is because these saline waters do not exist in the same formations in the rest of the plateau and also because of the presence of (1) high-quality surface waters in the Columbia, Snake, and Yakima Rivers and (2) high-production, good-quality shallow aquifers. Therefore, locally, there appears to be little incentive to use deeper saline waters, especially those waters in the low-production flow tops of the Grande Ronde Basalt found in the reference repository location and vicinity.

Assuming that in the future an economic or cultural incentive arises that would cause someone to use the deeper saline waters beneath the Hanford Site for agriculture, the suitability of water still depends on factors such as the crop produced, soil conditions, and irrigation practices. Because soils at the Hanford Site are, in general, coarse grained and have reasonably good drainage characteristics, it appears that the opportunity exists, with a proper water budget and deep leaching programs, for higher salinity waters to be used in production of more salt-tolerant crops. This may seem more realistic because waters of similar and higher salinity are used for irrigation elsewhere in the arid United States. However, the use of salinity comparisons alone can be misleading.

The following aspects of salinity should be addressed:

- Total dissolved salt content of the irrigation water and its physiological influence on plants.

- Ionic composition of the dissolved salts as it influences soil structure and drainage.

The specific conductivity of Grande Ronde Basalt ground waters places them in the high salinity class as previously stated. This means that only the more salt-tolerant crops could be grown and only if strict water management practices were implemented. Soils on which waters of such high salinity are used require frequent deep leaching to prevent salt accumulation in the root zone (Israelsen and Hansen, 1962, pp. 223-226; Allison, 1964, pp. 143-146). This requries a soil having good infiltration characteristics. The composition of dissolved salts, specifically the ratio of sodium to calcium plus magnesium, influences soil drainage. The sodium adsorption ratio is used as an indicator of this water-quality condition. Even for the most saline irrigation waters used in the arid western United States, sodium adsorption ratio values are typically not greater than 20 (Allison, 1964, p. 144). The sodium adsorption ratio of Grande Ronde Basalt ground water is in the 30's and 40's; within and adjacent to the reference repository location, the sodium adsorption ratio for Wanapum Basalt ground water ranges from the high 20's to the low 40's. The significance of this is that, with long-term use, the natural calcium carbonate in the soils would be leached away; the soils would then become dominated with sodium and lose their good soil structure. This results in plugging of soil pores, and then deep leaching to remove salts would be prevented. The only alternatives would be to add gypsum periodically to the soil or to reclaim with a low-sodium adsorption ratio, high-salt water such as is done in California where seawater is used. In essence, the deeper saline waters beneath the reference repository location could not be used without treatment of the water or soils.

In addition to sodium and salinity hazards, boron is of special consideration. Boron concentrations range from approximately 0.4 to 3.5 milligrams per liter in the Wanapum and Grande Ronde Basalts. Most concentrations in the Grande Ronde Basalt range between approximately 2.0 and 3.5 milligrams per liter. Within the upper and middle Wanapum Basalt, boron concentrations are approximately 0.5 milligram per liter. This value increases to approximately 1.5 milligrams per liter in the lower Wanapum Basalt. Boron concentrations in Grande Ronde Basalt and lower Wanapum Basalt ground water places them, depending on classification used, in the poorest classes for this parameter (Israelsen and Hansen, 1962; Allison, 1964). Only the most tolerant crops could be grown using these waters and then only with a good deep-leaching program.

In summary, Grande Ronde Basalt and lower Wanapum Basalt ground water in the reference repository location is considered unsuitable for agricultural use or human consumption without treatment. High salinity, fluoride, and boron concentrations directly affect the quality of crops grown and the high sodium adsorption ratio affects the ability of the soil to maintain the good drainage necessary to leach salts. These waters might be used for selected crops with special water and soil treatment. The high fluoride concentrations present in ground water of the Wanapum and Grande Ronde Basalts beneath the reference repository location make these waters unsuitable for human consumption, using either existing or proposed drinking water standards.

6.3.1.1.10 Potentially adverse condition

"(3) The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets--if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system."

Stratigraphic and structural features that could contribute to the difficulty of characterizing or modeling the geohydrologic system of the reference repository location have been identified in the geologic setting (Columbia Plateau). Therefore, this potentially adverse condition is likely to be present at the reference repository location.

Sections 3.2 and 3.3 outline the basic geologic and hydrologic setting of the Hanford Site with emphasis on the reference repository location. Portions of these discussions address the types of geologic features known to exist in Columbia Plateau, some of which have been identified in or near the reference repository location. Such features can have varying effects on creating geologic complexity as well as impacting ground-water and solute movement. Section 4.1 summarizes plans for geohydrologic characterization directed at identifying these types of features (whichever may exist in or near the reference repository location) so that their influence on ground-water movement and modeling complexity can be evaluated. Section 6.4.2 outlines the approach used to model numerically the geohydrologic data.

The features shown in Figure 3-35 represent natural discontinuities in a layered basalt mass, which can introduce spatial changes (in either direction (anisotropic conditions) or position (heterogeneous conditions)) in the distribution of rock and hydrologic properties. The existence of any one or more of these features and their possible effects on ground-water movement, rock stability, and repository design and (or) construction are a primary focus of the site-characterization program. Inferred or known tectonic structures in the Cold Creek syncline have been reported in Myers (1981) and Caggiano and Duncan (1983) and are discussed in Subsection 3.2.3.3.

6.3.1.1.11 Disqualifying condition

"A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel."

A final conclusion on this disqualifying condition for pre-waste-emplacement ground-water travel time is not possible at this time, because additional data are needed to define more clearly the geohydrologic properties of the deep basalts in and surrounding the reference repository location. However, based on available data and current understanding of the ground-water system, the pre-waste-emplacement ground-water travel time to the accessible environment along pathways of likely and significant radionuclide travel has a high likelihood of exceeding 1,000 years. The evidence does not support a finding that the reference repository location is disqualified (Level 1).

Ground-water travel time

A suite of pre-waste-emplacement ground-water travel-time models (Clifton, 1986) has been developed in support of this environmental assessment. These models explicitly estimate the uncertainty in the predicted travel times. Subsection 6.4.2.6.1 discusses the inputs to and results of one of these travel-time models. This model accounts for three-dimensional ground-water flow in the layered basalt sequence above the Cohassett flow interior. The results presented in Subsection 6.4.2.6.1 form the basis for the findings on this disqualifying condition.

The principal result of the analyses in Subsection 6.4.2.6.1 indicates there is a high likelihood (i.e., a probability of at least 0.97) of pre-waste-emplacement ground-water travel time to the accessible environment exceeding 1,000 years. Some of the predicted travel times in Clifton (1986) and Subsection 6.4.2.6.1 are in excess of 100,000 years. The prediction of travel times significantly in excess of 1,000 years adds confidence to the above estimate of exceedance probability. In determining this probability, travel time through the Cohassett flow interior is not taken into account for reasons of conservatism. The conceptual model used as a basis for the travel-time analysis in Subsection 6.4.2.6.1 considers ground-water flow in the basalt flow tops overlying the Cohassett flow interior. These flow tops are considered to be the predominant pathways of likely and significant radionuclide travel following repository closure. It is possible that other pathways of likely and significant radionuclide travel exist in the basalt sequence beneath the Hanford Site (e.g., vertically oriented, through-running fracture zones). However, direct evidence for the occurrence of such pathways in the deep basalts beneath the reference repository location does not exist. If site characterization proceeds, the collection and analysis of new data should allow pathways, including basalt flow tops, that could be significant conduits for radionuclide travel to be identified (see Section 4.1).

Radionuclide releases

The capability of the reference repository location to meet radionuclide release requirements set forth in Section 960.4-1 of the General Siting Guidelines (DOE, 1984a) depends on a number of factors and characteristics, including performance of the engineered barriers (e.g., waste package and repository seal system), ground-water flow paths and travel times, radionuclide inventory, radionuclide half-life, and radionuclide solubility and sorption.

The solubility of radionuclides in a ground-water system and the sorption of these radionuclides on the surrounding rock are important factors in understanding potential radionuclide releases because they control the rate and amount of radionuclide releases to the ground water and, thus, radionuclide transport to the accessible environment. For example, sorption is a natural chemical or physical process that can significantly retard radionuclide movement through the rock and minerals contacted and, in effect, make radionuclide travel times much longer than that of ground water. Practically all radionuclides in nuclear waste have been experimentally shown to exhibit some degree of sorption. Because of this, it is important to understand this geochemical characteristic of the reference repository location.

Laboratory measurements obtained to date suggest that the basalts beneath the Hanford Site exhibit favorable radionuclide sorption characteristics (Salter et al., 1981; Salter and Jacobs, 1982). This results from the sorptive capacity of many primary and secondary minerals in the basalt system. Based on preliminary data, two radionuclides (carbon-14 and iodine-129) appear to be nonsorbing and, therefore, are expected to travel at the velocity of ground water. (The sorptive and transport characteristics of other radionuclides; e.g., technetium-99, selenium-79, neptunium-237, plutonium-239 and -242, and tin-126, are also being studied (Subsection 6.4.2.3.2).) Radionuclides exhibiting sorptive characteristics would migrate more slowly than the ground water. In the case of carbon-14, preliminary data show that the release rate to ground water is expected to be controlled by its solubility characteristics, which depend on its chemical form in nuclear waste. Iodine-129, on the other hand, is highly soluble and nonsorbing. Preliminary estimates of the amounts of iodine-129 in the projected waste inventories show that this radionuclide is not expected to exceed the maximum allowable release limit specified in the U.S. Environmental Protection Agency standard (EPA, 1985).

The overall geochemical characteristics of the basalts appear favorable (Subsection 6.3.1.2) and preliminary calculations of radionuclide transport indicate a high probability of low radionuclide releases from a repository relative to the U.S. Environmental Protection Agency (EPA, 1985) limits. However, definitive statements concerning compliance with release requirements in Section 960.4-1 of the General Siting Guidelines (DOE, 1984a) cannot be made at this time. Additional data are needed to characterize fully the geochemical environment of the deep basalts and to quantify the uncertainties in such factors as solubility and sorption. Future characterization programs are planned to collect the required data (see Section 4.1).

Reducing data uncertainty

Reviews of the geohydrologic data base and (or) hydrology program in 1982 for basalt were conducted by several organizations, including the U.S. Nuclear Regulatory Commission (NRC, 1983b), U.S. Geological Survey (Robertson, 1983), Golder Associates (Golder, 1983b), Pacific Northwest

Laboratory (Burnham, 1983), as well as the U.S. Department of Energy (DOE, 1982e). Each organization identified uncertainties in available information. For example, the U.S. Geological Survey (Robertson, 1983, p. 5) noted: "We do not believe that the hydraulic conductivity, head gradient, and effective porosity data are sufficient or reliable enough to allow velocity calculations to be made with an accuracy of greater than approximately 2 or 3 orders of magnitude." All reviewers have noted that much additional information is needed before definitive statements can be made regarding ground-water travel times. This is the reason why an intense, ongoing, and planned data-collection program is under way.

Unless geohydrologic properties and energy gradients are perfectly known within a ground-water flow system, there must always be some uncertainty associated with the ground-water travel times predicted. The amount of uncertainty depends on how well the spatial variability of geohydrologic parameters are known. This, in turn, depends on the amount and quality of available data defining the flow system. Thus, to reduce the uncertainty in a predicted ground-water travel time, it is necessary to provide a higher degree of spatial resolution of hydrologic parameters within the ground-water system.

Uncertainties in the areal and stratigraphic (vertical) distribution of hydrologic properties and the geohydrologic setting of the reference repository location are being addressed through comprehensive, ongoing, and planned field studies (see Section 4.1). These studies include the following:

- Tests for large-scale measurements of hydrologic properties (DOE/NRC, 1983).
- Shallow and deep piezometer installations around the reference repository location to measure hydraulic heads and their temporal changes.
- Identification and monitoring of hydraulic heads in regional wells off the Hanford Site.
- Performance of additional tracer tests to better understand the effective porosity in basalt and how a radionuclide might disperse or spread.
- Additional small-scale hydrologic tests in single and dual boreholes.
- Additional tests to determine the effect of drilling mud on hydrologic test results.
- Updating and refining the hydrologic conceptual model for the Hanford Site and vicinity.
- Hydrologic testing in the exploratory shafts to evaluate geohydrologic properties and variations in fracture characteristics of a basalt flow interior (Rockwell, 1983a).

Uncertainties regarding the geochemical environment and its effects on radionuclide sorption are also undergoing continued research (see Subsection 4.1.1.5). Some specific items being investigated are listed below.

- Geochemical modeling of the basalt and ground-water system.
- Evaluation of ground-water sampling techniques and quality.
- Field and laboratory Eh (i.e., reduction and oxidation potential) measurements.
- Possible influence of fluoride, organic carbon, dissolved gas (methane), and colloids on radionuclide solubilities and transport.
- Possible radiation-induced processes enhancing radionuclide mobility.
- Sorption studies of significant radionuclides on minerals likely found along ground-water flow paths.
- Steady-state solution concentrations for significant radionuclides.
- Thermodynamic properties of significant minerals and alteration products.

If site characterization proceeds, new geohydrologic data will become available and data uncertainties will change according to research findings and the level of detail examined. Geohydrologic concepts were rather simple and the perceived uncertainty appeared small when little was known about the Columbia River Basalt Group. Additional data have since provided a better assessment of the magnitude of these uncertainties in the geohydrologic system. The combination of existing information and planned data should be able to determine if basalt does or does not meet performance requirements. As additional data become available, they will be integrated into performance assessment studies so that ground-water travel times and radionuclide-transport rates can be more reliably estimated.

As part of the research into understanding ground-water movement in basalt, an interagency hydrology working group was formed in 1983. This group consists of representatives from the U.S. Geological Survey, Pacific Northwest Laboratory, Basalt Waste Isolation Project, and U.S. Department of Energy who are sharing data and conducting computer model studies to estimate more closely hydrologic properties and ground-water flow dynamics within and surrounding the Pasco Basin. This working group is not involved in generating site-characterization data, including input to ground-water travel times. However, information derived from this type of cooperative activity between the U.S. Department of Energy and independent technical peers might be used in the future to help refine data inputs and boundary conditions to ground-water travel-time calculations.

6.3.1.1.12 Conclusion on qualifying condition

A final conclusion on the qualifying condition for geohydrology cannot be made based on available data. However, it is believed that the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3). The present and expected characteristics of the geohydrologic setting of the reference repository location appear compatible with the containment and isolation of nuclear waste. Expected radionuclide releases from the engineered system into the accessible environment are likely to meet regulatory requirements.

The factors supporting this preliminary finding are listed below.

- There is a high likelihood that ground-water travel times to the accessible environment will exceed 10,000 years along flow paths of likely radionuclide travel. Some of the travel times in the deep basalts are expected to be quite long (i.e., in excess of 100,000 years). If the travel time through the Cohassett flow interior of the repository horizon is taken into account, the ground-water travel times to the accessible environment are expected to be longer.

- The geohydrologic system is expected to be characterized and modeled with the required confidence needed for licensing decisions. Currently, ground-water conceptual and numerical models are developed and favorable hydrologic conditions appear to exist in the reference repository location. Examples of these conditions are low hydraulic gradients in the deep basalts (10^{-3} to 10^{-5} meter per meter (10^{-3} to 10^{-5} foot per foot)), and apparently low hydraulic conductivities in basalt flow interiors (equal to or less than 10^{-10} meter per second (10^{-5} foot per day)).

- The geochemical characteristics of the deep geohydrologic system appear favorable for limiting radionuclide releases and migration and extending waste canister lifetimes. Reducing conditions in the ground water and the presence of smectite clays and zeolites contribute to radionuclide retardation. In addition, under repository conditions, the basalt itself will likely alter to a variety of clays and zeolite phases that enhance radionuclide sorption.

- Ground-water resource potential in the deep basalts appears to be much smaller compared to available shallow ground-water and surface-water resources. In addition, the deep ground water has sodium, boron, and salinity concentrations that could adversely affect irrigated crops. Fluoride concentrations exceed (by a factor up to 20) the safe drinking water standards established by the U.S. Environmental Protection Agency (EPA, 1976).

- The general geologic and climatic characteristics that would affect the deep geohydrologic system have been identified. These characteristics are considered favorable, although structural and stratigraphic features of the Columbia Plateau could contribute to the difficulty of characterizing or modeling the geohydrologic system. There is no evidence to suggest that the long-term, low-average rate of deformation (40 to 80 meters (130 to 260 feet) per million years), arid climate, and rates of geomorphic processes during the past few hundred thousand years are expected to change within the central Pasco Basin over the next 100,000 years. Therefore, no significant change in the nature and rates of geohydrologic processes are expected during the same time.

- The engineered barrier system, in concert with natural site characteristics, is expected to constrain radionuclide releases to a small fraction of allowable limits.

The above factors are based on an extensive, although preliminary, data base and a general understanding of ground-water movement in and around the reference repository location. Uncertainties are identified in Chapters 2 and 3, as well as in Sections 6.2, 6.3, and 6.4. Uncertainties related to the factors above include the following:

- Lateral and vertical distribution of hydrologic properties and hydraulic head values with emphasis on vertical hydraulic conductivities of basalt flow interiors and effective porosities of flow tops and flow interiors.

- Lack of a single or narrow range of quantified conceptual models to describe ground-water flow.

- Understanding of the geohydrologic setting of the reference repository location and potential influence of any stratigraphic and structural discontinuities.

- Influence of possible complexing agents and radiation processes on radionuclide-sorption characteristics.

- Sorption behavior of significant radionuclides on site-specific minerals.

- Representativeness of expected model-generated ground-water travel times and radionuclide-transport rates.

- Steady-state solution concentrations for significant radionuclides with site-specific minerals.

6.3.1.2 Geochemistry (Section 960.4-2-2)

6.3.1.2.1 Qualifying condition

"The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology."

6.3.1.2.2 Evaluation process

The expected geochemical characteristics of the basalts at the Hanford Site represent one of the most favorable aspects of basalt for assuring the safe containment and long-term isolation of nuclear waste. The most credible mechanism for radionuclide release from a repository in basalt is dissolution of the nuclear waste form in ground water and subsequent transport through the engineered and geohydrologic systems. The most important chemical processes that control potential releases and transport are radionuclide sorption and dissolution of radionuclide-bearing phases. These processes are highly dependent on the geochemical environment of a repository site.

Laboratory studies have focused on evaluating the steady-state concentrations of radionuclide releases to ground water over a range of site-specific conditions and in the presence of basalt and reference engineered barrier materials (Apted and Myers, 1982; Myers et al., 1984; Grandstaff et al., 1984; Coles and Apted, 1983; Schramke et al., 1984). Sorption studies on primary and secondary (alteration) minerals of site-specific basalts and on interbed materials show that these mineral phases have high sorptive capacity for many radionuclides significant to repository performance (Salter et al., 1981; Barney, 1981, 1984; Barney et al., 1983; Salter and Jacobs, 1982). These studies were conducted as batch experiments in which a single average K_d (distribution coefficient) value resulted. In general, each of several species of a specific radionuclide may be present in ground water and may have different associated K_d values. The effect of multiple species of a radionuclide on sorption will be addressed by future testing (e.g., flow-through column experiments) (see Subsection 4.1.2.6).

Laboratory tests have been conducted to evaluate the control on geochemical parameters (e.g., pH, oxidation potential (Eh), and ground-water composition) by basalt-ground water reactions (Apted and Myers, 1982; Lane et al., 1983a, 1983b; Jantzen, 1983; Grandstaff et al., 1984). In particular, these tests have indicated that basalt rapidly imposes a reducing environment in the deep ground waters. The capability of basalts beneath the Hanford Site to impose reducing conditions has been estimated experimentally over a temperature range of 100 to 300°C (212 to 572°F) by Moore et al. (1985) and Lane et al. (1983b). The study by Moore et al. (1985) showed that a calculated Eh of approximately minus 0.7 volt (based on measured sulfide and sulfate concentrations at 300°C (572°F)) was established in synthetic Grande Ronde Basalt ground water after reacting with basalt from the Umtanum flow at 300°C (572°F). Further investigation of the reducing capability of basalts beneath the Hanford Site over a wider range of water to rock ratios and temperatures is under way. Theoretical studies of Jacobs and Apted (1981), Apted and Long (1982), and Apted and Myers (1982) suggest that Eh values within the range of minus 0.4 plus or minus 0.1 volt at a pH of 9.2 plus or minus 0.5 at 60°C (140°F) are expected in this geochemical environment. The experimental work has been completed with crushed basalt, which is typical of the waste package packing material, but not the host rock.

Evidence pertaining to the actual Eh conditions in Hanford Site ground waters is provided by the (1) nature of alteration minerals coating fractures in the basalts, (2) measured concentrations of redox-sensitive species in the ground water, and (3) direct measurements of ground-water Eh. When considered together, these three lines of evidence give useful estimates of the ambient ground-water redox environment in the reference repository location and vicinity.

Investigations of alteration mineral assemblages in basalts beneath the Hanford Site have been conducted by Ames (1980), Teague (1980), Benson and Teague (1982), and Benson et al. (1978). The assemblages consist predominantly of clinoptilolite, cristobalite, quartz, and an iron-rich smectite. Over 20 other minerals occur in subordinate amounts (Deutsch et al., 1982b). The iron-bearing materials in these assemblages are particularly important because their solubilities may control the concentrations of ferrous and ferric species, and the Fe^{2+}/Fe^{3+} ratio may influence or control the redox potential of the ground waters. Iron-bearing alteration minerals in the Columbia River Basalt Group include chlorite, celadonite (an iron-rich illite), smectite (an iron-rich variety called nontronite by Ames (1980)), vermiculite, and pyrite. In addition, calcite may contain several weight percent ferrous iron (Ames, 1980) and hematite may have been identified within a smectite (Benson and Teague, 1982). Pyrite is commonly found in fractures but occurs only in minor amounts. Dill et al. (1986) have shown that an inverse relationship exists between the concentrations of dissolved ferrous iron and dissolved sulfide in Hanford Site ground waters, suggesting solubility control of their concentrations by pyrite (or another iron sulfide mineral). If pyrite is in equilibrium with ground waters, then an upper limit Eh of approximately minus 0.26 volt (at a pH of 9 and temperature of 25°C (77°F)) is indicated.

Concentrations of the oxidized and reduced species of an element dissolved in ground water can provide additional useful information on the redox state of a system. There are three redox couples for which either quantitative or qualitative concentration data are available for Hanford Site ground waters: (1) Bisulfide/sulfate, (2) methane/carbon dioxide, and (3) methane/carbon monoxide. Calculated values for the Eh of ground waters based on the concentrations of species in the above couples (Dill et al., 1986) are as follows:

Bisulfide/sulfate	-0.37 to -0.41 volt
Methane/carbon dioxide	-0.42 to -0.52 volt
Methane/carbon monoxide	less than -0.38 volt

These values were calculated using a temperature of 60°C (140°F) and a pH of 9. Carbon monoxide concentrations are below detection, fixing an upper limit on Eh for the methane/carbon monoxide couple. Although there is some scatter in the Eh values predicted by these couples, the data consistently indicate a generally reducing environment for ground waters in contact with basalts beneath the Hanford Site.

Direct measurements of Eh in ground waters from the Hanford Site provide additional indications of ambient redox conditions. Unfortunately, reliable measurements are difficult to obtain from natural water due to slow reaction kinetics and a general lack of reversibility for many redox couples. In natural waters, Eh may actually be a composite value resulting from interactions among several redox couples that are not in equilibrium with each other (Stumm and Morgan, 1981; Drever, 1982). Sampling may disturb the actual Eh of the ground waters if gases are gained or lost from the sample. The range of Eh values measured for ground waters from confined aquifers at the Hanford Site is approximately minus 0.2 to plus 0.3 volt, with the distribution of values skewed heavily in favor of the more negative values (Early et al., 1985). The measured values for Eh are considerably higher than those indicated by the redox couples discussed earlier and are higher than the maximum value indicated by pyrite equilibrium. This skewed distribution might indicate air contamination of some of the samples. However, even the most negative Eh value measured is still more positive than the Eh indicated by the redox couples. The reasons for this difference are being investigated. Sampling of ground waters is continuing with a major emphasis devoted to refining the estimates of ambient Eh conditions.

Despite the scatter in Eh values estimated from alteration mineralogy, redox couples, and direct measurement, the majority of data indicate that the ambient redox environment at the Hanford Site is reducing. A similar result has been determined by Arnorsson et al. (1983) in a study of Icelandic geothermal systems. The lower temperature Icelandic systems are analogous to the basalt and water environment at the Hanford Site (Ulmer and Grandstaff, 1984). Arnorsson et al. (1983) determined an ambient Eh of approximately minus 0.4 volt at 50°C using fluid analyses data and the bisulfide/sulfate redox couple discussed above. The Arnorsson et al. data also indicate a linear relationship between temperature and the ratio of Eh-pH over a temperature interval of 25 to 250°C (77 to 482°F).

Based on thermodynamic arguments (Early et al., 1982), many radionuclide-bearing solids containing redox-sensitive elements (e.g., technetium, uranium, neptunium, and plutonium) decrease in solubility with decreasing redox potential. Lower oxidation states of these elements are also more strongly sorbed on basalts and interbed materials than oxidized species (Barney, 1984; Ames and McGarrah, 1981; Vandergraaf et al., 1984). Because of lower solubilities and greater sorption of reduced radionuclide species, transport of radionuclides is decreased in a reducing environment.

Because redox-sensitive solution species may or may not respond to redox-controlling reactions imposed by the basalt plus ground-water system, each radionuclide of concern must be demonstrated to be responsive to redox conditions in this system. Preliminary tests on technetium (Bondietti and Francis, 1979; Coles and Apted, 1983), uranium (Grandstaff et al., 1984), and neptunium (Meyer et al., 1984; Susak et al., 1983) have confirmed that basalt can cause the reduction of these elements to less soluble and more highly sorbed chemical species.

Solubilities of many radionuclide oxides and hydroxides in ground waters (e.g., AmO_2, $Am(OH)_3$, $PuO_2 \cdot xH_2O$, NpO_2OH, and $UO_2(OH)_2$) are observed to decrease as the pH of the ground water increases (Allard, 1982; Rai, 1984; Kim et al., 1984a). This observation is complicated by potential formation of complexes with inorganic anions and organic complexing agents and by redox reactions. However, the relatively high pH values (compared to other natural ground waters) measured in deep basalts (9.2 plus or minus 0.5) should decrease radionuclide mobility.

Regarding the available geochemical data base, an independent review by Burnham (1983, p. VI) states: "Analysis of geochemical data leads us to conclude that on the basis of the DOE siting guidelines, the Hanford basalt has several favorable attributes and no seriously unfavorable ones. Favorable attributes include pre-emplacement reducing conditions, neutral pH, average radionuclide complexing potential, and alteration mineralogy that increases adsorption potential and lowers permeability."

It should be noted that the U.S. Nuclear Regulatory Commission has presented arguments that emphasize the uncertainty of Eh estimates for the basalt geochemical system (NRC, 1983b). The U.S. Department of Energy recognizes the need to refine these estimates and is actively engaged in continuing laboratory and field tests to confirm the most representative model.

6.3.1.2.3 Favorable condition

"(1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years."

This favorable condition appears to be present at the reference repository location, since the existing and expected geochemical processes in basalt appear to retard effectively the movement of most radionuclides significant to repository performance. (Carbon-14 and iodine-129 are the only exceptions.)

During the Quaternary Period the geochemical process that has dominated within the Columbia River Basalt Group is low-temperature (approximately 60°C (140°F)) diagenesis, involving basalt-ground water reactions (Benson and Teague, 1982). These reactions involve slow alteration of primary basaltic phases, such as glassy mesostasis and pyroxene, coupled with precipitation and growth of secondary alteration phases (e.g., zeolite, clay, amorphous iron hydroxides, silica, and pyrite). The expected continuation of this process for the next 100,000 years would assure control of pH at mildly alkaline conditions and a reducing Eh, as well as maintaining a low-ionic-strength (less than or equal to 0.018) (DOE, 1982e) ground water. These conditions are favorable toward the ability of the repository to isolate waste.

Laboratory, field, and calculation studies have been completed on the basalt-ground water system at low temperatures (less than 100°C (212°F)) (Benson and Teague, 1982; Deutsch et al., 1982a; Jacobs and Apted, 1981; Smith et al. (1980); Jantzen, 1983) and higher temperatures (greater than 100°C (212°F)) (Apted and Myers, 1982; Myers et al., 1984; Grandstaff et al., 1984; Lane et al., 1983a, 1983b). The results of these initial investigations indicate that ground-water composition, including Eh and pH, are rapidly controlled and buffered by the coexisting basalt. Furthermore, the expected Eh of minus 0.4 plus or minus 0.1 volt and pH of 9.2 plus or minus 0.5 at approximately 60°C (140°F) (see Subsection 6.3.1.2.2) would provide a favorable environment for the isolation of most radionuclides significant to repository performance. Carbon-14 and iodine-129 are the only exceptions. Note that these experiments were completed with fresh, crushed basalts, and further work is being completed to determine Eh-pH buffering capacity of intact basalts, as well as the effects of long-term hydrothermal alteration on basalt Eh-pH buffering capacity (see Subsection 4.1.2.6). The secondary minerals produced by this slow alteration process are found to fill the fractures and vesicles of the basalts. The existing secondary phases, which are also the secondary phases expected to form after repository closure (Subsection 6.3.1.2.5) have been demonstrated to adsorb strongly and, hence, retard the movement of many radionuclides (Salter et al., 1981; Barney, 1981; Salter and Jacobs, 1982). The possible ground-water pathways through basalts are discussed in Section 3.3.2. The low concentrations of many potential complexing species (chloride, sulfate, and carbonate) will contribute to the formation of relatively insoluble radionuclide-bearing solids, and tend to reduce significantly the migration of radionuclides from the engineered barriers. Another potential complexing agent is fluoride, which does exist in relatively high quantities. However, the importance of fluoride complexation in deep ground water is reduced because of the alkaline pH (Early et al., 1982; Nash and Cleveland, 1984).

The chemical reducing agent (hydrazine) has been used in some laboratory studies to convert radionuclides to reduced species. The effects of hydrazine on radionuclide sorption behavior are being evaluated to confirm the validity of existing data. Sorption experiments are in progress for radionuclides under reducing conditions that do not rely on the presence of hydrazine.

6.3.1.2.4 Favorable condition

"(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes."

This favorable condition is expected to be present at the reference repository location. The data suggest that conditions promoting precipitation and sorption of radionuclides are characteristic of the prevailing geochemical conditions. The extent and role of organic material (in interbeds and associated flow tops) in the formation of radionuclide complexes are unknown.

The effect of the ambient site geochemical environment on precipitation and sorption of radionuclides is favorable for many radionuclides (see Subsection 6.3.1.2.3). Extensive data are available on sorption measurements for a wide variety of radionuclides, mineral substrates, ground-water compositions, and other experimental conditions. These data show that radionuclides that exist as metallic ions in ground water are strongly sorbed on basalt, secondary minerals, and interbed minerals.

The existence of organic complexing agents and the formation of colloids within the geologic setting is not yet understood. The difficulty of obtaining representative deep ground-water samples from mud-drilled boreholes has prevented the identification and study of organic species. Therefore, the extent and significance of organic complexants with respect to radionuclide transport remains to be quantified. In addition to colloids that may occur naturally in deep ground waters, colloids may be generated by degradation of barrier materials (e.g., packing, container, or waste-farm materials). These colloids could potentially form pseudocolloids containing waste radionuclides. Because colloids are mechanically filterable (Stumm and Morgan, 1981; Olofsson et al., 1982) and settle due to gravity (Apps et al., 1982), it is expected that colloids formed in a basaltic environment will tend to coalesce onto solids or be physically removed from the ground water before the colloid can contribute significantly to radionuclide migration. A more definitive resolution of this question is expected when a ground-water sampling program is conducted from the exploratory shafts, from boreholes drilled without mud, and from results of the ground water-basalt-radionuclide interaction testing (see Subsections 4.1.1.5, 4.1.1.6, and 4.1.2.6).

6.3.1.2.5 Favorable condition

"(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport."

This favorable condition appears to be present at the reference repository location, since temperature increases around the repository are not expected to cause significant changes in the sorptive properties of secondary minerals. Although increases in repository temperatures will probably induce minor dissolution of the basalt, sorptive alteration minerals are expected to form nearly simultaneously from the dissolution products.

Experimental evidence for coupled dissolution and precipitation reactions in basalt-ground water systems is given in Moore et al. (1985), Lane et al. (1983a), and Apted and Long (1982). Studies of Icelandic geothermal systems that are possible natural analogs for a repository in basalt (Ulmer and Grandstaff, 1984) indicate that basalt dissolution (occurring over a time interval greater than 100,000 years) is accompanied by contemporaneous secondary mineral formation (Fridleifson, 1983).

The alteration minerals formed from hydrothermal reaction of basalt at high temperatures (greater than 100°C (212°F)) (Apted and Myers, 1982; Allen et al., 1983; Lane et al., 1983b; Grandstaff et al., 1984) are similar to the existing alteration mineral assemblages that line fractures and fill vesicles of the basalts (Smith et al. 1980) and the lower temperature (approximately 60°C (140°F)), diagenetic alteration minerals that continue to form in basalts at the reference repository location and vicinity (Benson and Teague, 1982). This result is expected for the hydrothermal alteration of basalts up to at least 200°C (392°F) (Winkler, 1974; Giggenbach, 1981). Typical alteration mineral assemblages include zeolites, clays, feldspars, silica phases, pyrite, and other minerals. Because of the similarity of high-temperature alteration phases (the identical phases in many cases) to those in the basalt, any change in the thermal conditions of a repository is not expected to cause significant reduction in the sorption properties of alteration minerals in the thermal zone.

Subsection 6.3.1.3.6 discusses the potential effects of elevated temperatures in the vicinity of the repository on the irreversible dehydration reactions of hydrous secondary phases such as clays and zeolites. In general, this process (if it occurs at all) would be restricted to the zone of maximum thermal perturbation nearest the waste packages. Furthermore, experimental evidence does not indicate that significant hydrothermal alteration of existing clays to mixed layer smectite-illite clays (with reduced sorptive capacity for radionuclides) occurs in this geochemical environment (Wood et al., 1984, pp. 1 through 33).

6.3.1.2.6 Favorable condition

"(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved."

This favorable condition is expected to be present at the reference repository location, since preliminary calculations indicate less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years would be dissolved.

A hypothetical case was formulated and analyzed to demonstrate compliance with the favorable condition, because (1) the condition statement is based on simple convective release (described by flow rate times solubility) rather than diffusional release and (2) the condition is assessed on the assumption that engineered barriers are not present. This illustrates the effectiveness of the site rather than the combination of the site and engineered barriers.

The requirement in this favorable condition is stated as a percentage, so the reference inventory for the analysis is immaterial. Therefore, 1,000 metric tons (1,100 tons) of heavy metal were utilized for convenience. The total curie inventory at 1,000 years is 1.6×10^6 curies for composite spent fuel (DOE, 1979), so the allowable annual release is 0.001 percent of 1.6×10^6, or 16 curies per year.

Volumetric water flow rate was estimated by assuming the vertical conductivity is 10^{-11} meter per second (10^{-6} foot per day), buoyant gradient is 0.03, and water flowing through 10 square meters (108 square feet) around each waste package becomes saturated with radionuclides (equivalent to assuming that water out to a distance of approximately 1 meter (3 feet) from the package becomes saturated). The total water flow rate (W) is determined by:

$$W = \left(10^{-11}\ \frac{\text{m}}{\text{sec}}\right)\left(3 \times 10^{-2}\ \frac{\text{m}}{\text{m}}\right)\left(3.2 \times 10^{7}\ \frac{\text{sec}}{\text{yr}}\right)\left(10\ \frac{\text{m}^2}{\text{pkg}}\right)\left(10^{3}\ \frac{\text{L}}{\text{m}^3}\right)\begin{pmatrix}\text{600 pkg}\\ \text{(equivalent to}\\ \text{1,000 t of}\\ \text{heavy metal)}\end{pmatrix} = 58\ \text{L/yr}\ (15.3\ \text{gal/yr}) \qquad (6\text{-}1)$$

The hydrologic parameter assumptions are reasonably conservative (Subsection 6.4.2.6.1), and the conservative solubilities from Salter and Jacobs (1983) were then used to estimate release rates, which are the product of water flow rate and solubility. The rates for the highest inventory radionuclides, representing nearly 97 percent of the total, are given below.

Radionuclide	Molar solubility	Fractional release rate per year	Release rate, curie per year
^{239}Pu	10^{-5}	3.0×10^{-8}	8.0×10^{-3}
^{240}Pu	10^{-5}	7.0×10^{-8}	2.8×10^{-2}
^{241}Am	10^{-9}	5.8×10^{-10}	4.8×10^{-4}

The total release rate will not reach 16 curies per year from the contributions of the actinides. The dominant radionuclide in this analysis is iodine-129, which has a low inventory but a conservative solubility estimated at 10^{0} molar. This yields a hypothetical fractional release rate of 3.95×10^{-2} per year, or approximately 1.3 curies per year. No other radionuclide approaches this release rate, though some radionuclides (e.g., carbon-14, selenium-79, nickel-59, cesium-135) would each contribute a few hundredths of a curie per year to the computed total release rate. Release rates for several radionuclides with element solubilities in the range of 10^{-2} to 10^{-3} molar (e.g., carbon and nickel) are low because nonradioactive isotopes of these elements dominate the release. Overall, the total release rate is below 16 curies per year. Thus, based on this hypothetical case formulated expressly for judgment of compliance with the favorable condition, the condition is met. Note that the estimated release rates, including engineered barriers as stated in Subsection 6.4.2.7.1, are lower than the values obtained by this analysis.

6.3.1.2.7 Favorable condition

"(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation."

This favorable condition appears to be present at the reference repository location, since preliminary calculations indicate that releases of radionuclides to the accessible environment are at least 600 times lower than those cumulative releases calculated without retardation.

According to the definition of peak cumulative release, as found in the General Siting Guidelines (DOE, 1984a), this favorable condition refers to the maximum value of projected releases of radionuclides to the accessible environment in any 10,000-year interval. Thus, the ratio

$$\frac{\text{Cumulative release without sorption}}{\text{Cumulative release with sorption}} \geq 10 \qquad (6\text{-}2)$$

must be met in any 10,000-year interval. A hypothetical case based on typical spent fuel (DOE, 1979) was formulated and analyzed to assess compliance with the guideline.

The following assumptions were used in this analysis.

1. Containment duration is equal to zero.

2. All radionuclides are released instantly.

3. Dispersion is ignored.

4. Ground-water travel time is is likely to exceed 10,000 years (see Subsection 6.3.1.1.3).

5. Pathway rock density is 2 grams per cubic centimeter (0.072 pound per cubic inch).

6. Pathway rock porosity is 0.2.

These assumptions were selected to be biased toward the conservative side of current estimates.

For the case of no sorption, release at the accessible environment is the total inventory of fission products and actinides after 10,000 years (i.e., arrival at the accessible environment). This value represents the numerator of the ratio in Equation 6-2.

With sorption, the entry of radionuclides into the accessible environment will occur as a series of pulses at times equal to ground-water travel time multiplied by the retardation factor for the particular radionuclide (i). The retardation factor (R) is given in the following equation.

$$R_i = 1 + \frac{\rho}{\theta} \times K_{d_i} = 11\ K_{d_i} \qquad (6\text{-}3)$$

where

ρ = density
θ = porosity
K_d = distribution coefficient (Salter and Jacobs, 1983).

Compliance with the favorable condition is achieved if the denominator of the requirement ratio (Equation 6-2) is less than one tenth the inventory at any 10,000-year interval. Radionuclides that cannot make a substantial contribution toward exceeding this value need not be considered. Inspection of the general expression (applicable to isotopes that are not being formed by decay of other isotopes)

$$\text{Cumulative release}_i = (\text{initial inventory})_i \times \exp\left[-\frac{0.693 \times T_{GW} \times R_i}{(\text{half-life})_i}\right] \qquad (6\text{-}4)$$

where

T_{GW} = ground-water travel time

indicates that to be significant, a radionuclide must have a high initial inventory, a low retardation factor, and a long half-life. Daughter products (e.g., radium-226) increase in inventory during the first few hundred thousand years after repository closure, but their inventories are never sufficient to have a significant effect on guideline compliance. The smallest value of the product, $T_{GW} \times R_i$, for radionuclides that sorb is 90,000 years. Values for most radionuclides that sorb are considerably greater than this and need not be considered except for those with high initial inventories. Radionuclides that do not sorb (e.g., iodine-129 and carbon-14) have small inventories and will not contribute significantly to total release. It should also be noted that the denominator term (Equation 6-2) represents the summation of releases within any 10,000-year interval; differences in retardation factor will restrict the potential for concurrent arrival of more than a few radionuclides in the same 10,000-year interval.

The three most prominent release pulses and the ratios are given below.

- For iodine-129 and carbon-14 at 10,000 years (no sorption)—1,400.
- For a group of uranium isotopes that arrive at 110,000 years—300.
- For neptunium-237 at 210,000 years—400.

The ratios of release without sorption to release with sorption exceed 10 by a factor of 30 or more. Compliance with the favorable condition is expected if estimates of site sorption capability are maintained.

It should be noted that additional retardation mechanisms (e.g., matrix diffusion) will tend to reduce further the migration rate of radionuclides in the ground-water flow system in the reference repository location and vicinity. Because of the difficulty of quantifying and verifying the effects of matrix diffusion, no credit was taken for this mechanism in the analysis of radionuclide releases.

6.3.1.2.8 Potentially adverse condition

"(1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system to the extent that the expected repository performance could be compromised."

Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered barrier system should not compromise expected repository performance. Therefore, this potentially adverse condition is not expected to be present at the reference repository location.

There are several geochemical factors in analysis of the ground water at the Hanford Site that need to be evaluated with respect to adverse effects on the performance of the engineered barrier system and release rate of radionuclides. Geochemical factors of the ground water that are under investigation include (1) fluoride content, (2) organic carbon content, (3) dissolved gas (especially methane) content, and (4) natural colloid content.

Estimates of radionuclide solubility based on expected repository conditions (Early et al., 1982) indicate that the range in measured concentrations of fluoride, chloride, sulfate, and dissolved silica do not seem to alter significantly the computed solubility results. Initial experimental studies by Cleveland et al. (1983a) suggested that plutonium solubility in ground water from a flow top in Grande Ronde Basalt in the Pasco Basin is enhanced by the high fluoride concentration of the water. A more recent study (Nash and Cleveland, 1984) concluded, however, that formation constants of plutonium fluoride complexes are much too small for these complexes to affect significantly the plutonium solubility in Hanford Site ground water. Related studies with neptunium and americium (Cleveland et al., 1983b) indicate that these radionuclides also display increased solubility in ground water from basalt compared to ground water from shale. These observations have not been confirmed and the studies were carried out in the absence of a solid basalt phase with no mechanism for controlling Eh or for evaluating the effects of colloids. In comparison, Early et al. (1982) recognize the possibility of inadequacies in the thermodynamic data base used for deriving solubility estimates. Ongoing site-specific studies using appropriate test oxidation states, reference barrier materials, basalt, and ground water are expected to help resolve this issue.

The potential significance of dissolved organic carbon content in the Hanford Site ground waters is that such material may form complexes with radionuclides, resulting in higher apparent solubilities and, hence, higher release rates. In addition to minor amounts of other organic constituents, Means (1982) found approximately 0.3 milligram per liter of fulvic acids in a single sample of ground water from Grande Ronde Basalt in borehole DC-6 (see Fig. 6-3). Olofsson and Allard (1983) performed a literature survey of information relative to complexing of actinides with naturally occurring humic and fulvic acids. This literature survey revealed that humic and fulvic acids can form very strong complexes with all oxidation states of these radionuclides. The organic carbon content and the relative importance of these acids in the basalt geochemical environment will be evaluated in planned characterization studies. In addition, the only organic characterization information available for Hanford Site ground waters is limited to total organic carbon analyses for approximately 50 samples. These results suggest that drilling fluid contamination leads to high total organic carbon values, but that ground waters from extensively pumped horizons usually have total organic carbon concentrations of less than 1 milligram per liter, a value consistent with the borehole DC-6 sample examined by Means (1982). Investigations will continue to characterize the organic carbon in ground waters by analyzing samples from boreholes drilled without organics (see Subsection 4.1.1.3).

Recently, dissolved methane at concentrations up to approximately 700 milligrams per liter has been measured in ground-water samples from several Grande Ronde Basalt flows within the reference repository location. Dissolved methane, by itself, probably does not constitute a problem as an organic complexant for radionuclides. However, gamma radiolysis of synthetic Grande Ronde Basalt ground water in the absence of basalt, containing approximately 700 milligrams per liter of dissolved methane, has demonstrated that high molecular weight organic solids (similar to polyethylene) may form under dose rates of 3×10^5 roentgens per hour. In the presence of basalt, however, initial test data indicate that these polyethylene-like organics are not formed (Gray, 1984). Testing is in progress to further identify reaction products in the presence of basalt and engineered barrier materials and their effect on radionuclide-release behavior.

The potential effects of alpha radiolysis on radionuclide migration from the engineered barriers will be studied. Theoretical studies of Neretnieks (1982) and Neretnieks and Aslund (1983) suggest that alpha radiolysis of water within a breached canister will lead to production of a strong oxidant, hydrogen peroxide. As a result, some redox-sensitive radionuclides may exhibit higher oxidation states in which sorption and precipitation reactions will be less effective means of retardation. The importance of alpha radiolysis in the repository environment and its impact on waste isolation is under investigation.

Several chemical processes will occur in the waste package environment and influence the stability of the waste package packing component, especially the sodium bentonite phase. The most important processes are dehydration, steam-bentonite reactions, hydrothermal alteration, and radiation effects. If these processes cause packing material alteration, it is necessary to determine the effect of alteration on packing material performance. In particular, it must be determined if bentonite alteration results in a substantial decrease in swelling capacity, an increase in permeability, and a loss of diffusional control of radionuclide transport in the packing.

The effects of dry heat on bentonite properties were investigated by Bradley et al. (1983), Borchardt (1977), and Palmer et al. (1983). Bradley et al. observed, after heating bentonite at 200°C (392°F), that its expansion capability was reduced by approximately 30 percent. This does not represent a substantial loss in swelling capacity, because the clay was still able to absorb seven times its weight in water. Borchardt (1977) observed that dry heating of smectites below 200°C (392°F) drove off only adsorbed or interlayer water. Bentonite structural water was not driven off until heated above 400°C (752°F). Similarly, Palmer et al. (1983) observed that structural water was not driven off below 370°C (698°F). Swelling capacity is not lost until structural water is removed from bentonite. Since estimates of waste package packing temperatures do not exceed 300°C (572°F), it is not expected that the dehydration process will eliminate or significantly reduce bentonite-swelling capacity.

Couture (1985) steam treated packing material mixtures (75 percent basalt and 25 percent bentonite by weight) up to 250°C (482°F) and then measured the permeabilities of these mixtures. Couture observed increased permeabilities as a function of increased steam temperatures. Permeabilities of 1 x 10^{-18} and 1 x 10^{-14} square meter (1.1 x 10^{-17} and 1.1 x 10^{-13} square foot) were measured for unsteamed and steamed packing materials, respectively, with an initial density of 1.7 grams per cubic centimeter (106 pounds per cubic foot). These values correspond to hydraulic conductivities of 10^{-11} and 10^{-7} meter per second (10^{-6} and 10^{-2} foot per day). At a density of 2.1 grams per cubic centimeter (131 pounds per cubic foot), a hydraulic conductivity of approximately 10^{-9} meter per second (10^{-4} foot per day) was measured for steamed packing. Following the experiments, the packing materials were allowed to expand freely in water and a significant loss of swelling capacity had occurred, resulting in the increased permeability.

An analysis has been performed to determine the effects of Couture's (1985) measured increases in permeability on the ability of packing to maintain diffusional control of radionuclide transport. Experiments are being conducted to determine if these effects are permanent. Measured diffusion coefficients for inert elements in packing material at 1.8 grams per cubic centimeter (112 pounds per cubic foot) at 90°C (194°F) are 1 x 10^{-9} square meter (1 x 10^{-8} square foot) per second (Relyea et al., 1985). Using the approach of Relyea and Wood (1984), a hydraulic conductivity of approximately 10^{-6} meter per second (10^{-1} foot per day) is necessary for diffusion to be the primary transport mechanism affecting fractional release rates. For cumulative releases over 10,000 years, assuming no sorption, the maximum to maintain diffusional control and radionuclide releases is approximately 10^{-9} meter per second (10^{-4} foot per day). Thus, for a packing material with a density of approximately 2.1 grams per cubic centimeter (131 pounds per cubic foot), steam treatment will not increase permeability enough to eliminate diffusional control of radionuclide transport.

Packing material and ground-water experiments have been conducted by Wood et al. (1982, 1984), Peacor et al. (1984) and Anderson et al. (1984). The data show that substantial reactions occur at 300°C (572°F) and relatively small amounts of reaction occur at lower temperatures. In the basalt-bentonite-ground water experiments, the major secondary phases formed are iron-rich smectites and zeolites. Bentonites are slightly enriched in potassium, which may indicate incipient transformation to illite. However, the alteration of bentonite to illite has not been clearly identified. Another possible reaction is the alteration of bentonite to iron-rich smectite. Anderson et al. (1984) performed experiments at 150°C (382°F) in the basalt-bentonite-steel-ground water system that was saturated with methane or irradiated or both. The X-ray defraction analyses of the solid phases showed some changes in the bentonite peaks, which are probably the result of cation exchange (e.g., calcium and magnesium for sodium). As with the Wood et al. (1982, 1984) experiments, an iron-rich smectite (nontronite) was formed. Peacor et al. (1984) performed bentonite-ground water experiments from 300 to 460°C (572 to 860°F) and observed substitution of calcium for potassium in the bentonite at 300°C (572°F). These data are relatively consistent and, when combined with observations of secondary minerals formed in the natural basalt environment, indicate that loss of swelling capacity and an increase in permeability are unlikely to result from hydrothermal reactions. The major mechanism for loss of swelling capacity should be the conversion of bentonite to illite. The potassium-poor basalt environment, the observed partitioning of potassium into other secondary minerals (e.g., zeolite), and the scarcity of mixed-layer smectite-illite clays in the host rock (Benson and Teague, 1982) support the hypothesis that illite alteration is unlikely to be a significant reaction in the waste package packing.

The effects of radiation on bentonite stability and swelling capacity have been investigated experimentally by Bradley et al. (1983), Anderson et al. (1984), and Haire and Beall (1979). Bradley et al. (1983) exposed dry bentonite to gamma radiation (total dose of 9.5×10^9 rads) for 40 days at 100°C (212°F). The expansion capability was reduced approximately 40 percent, which is not a significant loss of swelling capacity because bentonite could still absorb more than seven times its weight in water. Anderson et al. (1984) performed a hydrothermal experiment in the basalt-bentonite-steel-ground water system at 150°C (302°F) at a gamma dose rate of 4×10^4 rads per hour and total dose rates of 5 to 7×10^7 rads. No significant changes in bentonite stability or swelling capacity were observed under these conditions. Haire and Beall (1979) spiked saturated bentonite with einsteinium-253 at a concentration of 3.33×10^{-5} mole per gram. This corresponds to an alpha dose of 4.8×10^{11} rads and a dose rate of 3.2×10^9 rads per hour. Under these conditions, rapid loss of clay crystallinity was observed. An analysis of total dose and dose rates expected in the packing by Reed et al. (1985) indicate that these experimental conditions are extreme (e.g., the experimental dose rate is 10^5 to 10^8 times that of the calculated dose rate) and are not considered applicable to the evaluation of the effects of radiation on bentonite stability. In summary, the effects of radiation on packing material stability are not considered significant.

The effects of packing alteration on radionuclide diffusion coefficients are expected to be minimal. Diffusion can be divided into two parts: Physical transport and chemical processes (e.g., sorption). Factors that may influence physical transport include temperature, density, swelling capacity, and mineral type. Ground-water chemistry and mineral type would influence chemical sorption processes. Relyea et al. (1985) measured tritium and chloride diffusion coefficients through packing as a function of density and temperature. They observed that diffusion coefficient values were 10^{-9} to 10^{-10} square meter (10^{-9} to 10^{-10} square foot) per second, suggesting that diffusion by physical transport alone is not sensitive to temperature and density. The influence of bentonite-swelling capacity also appears to have little effect on diffusion processes. Eriksen and Jacobsson (1982) measured strontium diffusion coefficients in sodium bentonite and calcium bentonite clay; they were found to be the same despite the much greater swelling capacity of sodium bentonite relative to calcium bentonite. With regard to chemical processes that affect diffusion coefficients, the primary alteration phases expected in packing material are iron-rich smectites and zeolites (see discussion above on hydrothermal alteration products). Smectites are characterized by large specific surface areas (700 to 800 square meters per gram (3.4×10^6 to 3.9×10^6 square feet per pound)) and large cation-exchange capacities (0.9 to 1.1 milliequivalent per gram). Because the glass content of basalt in packing is 20 percent or more by volume (Long and WCC, 1984) and glass to smectite reactions will occur, the sorptive capacity of packing is expected to increase substantially with time.

A potentially adverse effect of ground-water chemical reactivity is corrosion of the waste container. Corrosion can occur in many modes; the following are being considered by the Basalt Waste Isolation Project: Uniform corrosion, pitting corrosion, crevice corrosion, intergranular corrosion, dealloying, and stress-corrosion cracking. These were chosen from literature surveys dealing with all corrosion modes considered significant for the containers over the full range of expected environments. The choice of corrosion modes is supported by other reviewers (Claiborne et al., 1985). Although testing will be performed for the selected corrosion modes, data obtained (Lumsden, 1985; Pitman, 1985; James, 1985) for ground-water conditions simulating a repository environment indicate that pitting and stress-corrosion cracking will not be active corrosion modes. These data are short-term test results and must be confirmed by additional long-term testing. Carbon steel is mildly susceptible to crevice corrosion or intergranular corrosion, and such corrosion modes have not been observed in tests with prototypic packing and anoxic ground-water environments. Dealloying would be active only in the alternative container material, cupronickel 90-10. Thus, uniform corrosion is expected to be the most probable active corrosion mode. An allowance for uniform corrosion is included in the carbon steel container design, which is expected to meet U.S. Nuclear Regulatory Commission requirements for containment time (NRC, 1985a) (see Subsection 5.1.4.2).

The ground-water composition expected to exist in the repository is benign with respect to corrosion of mild steel, as demonstrated by the test results. This is primarily due to the low oxygen content of the ground water. It is well known that the corrosivity of water toward steel is highly dependent on dissolved oxygen and is nearly negligible as the oxygen content becomes much less than 1 milligram per liter (Uhlig, 1971). Additionally, the low ionic content of the Hanford Site ground water reduces the possibility of localized corrosion forms (e.g., pitting and stress-corrosion cracking). Tests based on a Plackett-Burman statistical design (Anantatmula, 1985) have shown that increasing anion concentrations by more than a factor of two from expected compositions had no significant effect on corrosion in 1-month tests at 100 and 250°C (212 and 482°F).

Other dissolved gases can influence corrosion. Hydrogen sulfide (H_2S) can be very detrimental to high-strength steels, but hydrogen sulfide is not expected in the repository environment. This is because of the high ground-water pH that would convert the hydrogen sulfide to bisulfide. Methane will be present in the ground water at maximum concentrations of approximately 700 milligrams per liter. Corrosion tests have been performed with 3.45 megapascals (500 pounds per square inch) pressure of a 98-percent methane and a 2-percent nitrogen mixture. After 1 month of exposure at 100 and 200°C (212 and 392°F) in anoxic basalt and ground water, no pitting was observed. Corrosion rates were comparable to similar tests without methane at 200°C (392°F). The corrosion rate in methane at 100°C (212°F) was approximately 50 percent greater than a comparable test with no methane.

Corrosion tests in synthetic ground water containing methane also have been performed by Brookhaven National Laboratory (Anderson et al., 1984) at 150°C (302°F) with a gamma radiation flux of 3.8×10^5 rads per hour and without radiation. Pitting was observed in metallographic analysis to a maximum depth of 12 microns (4.7×10^{-4} inch) in the irradiation test and 8 microns (3.2×10^{-4} inch) in the nonirradiation test. The test time was 2 months. The dissolved oxygen content of the ground water in the Brookhaven tests was 0.2 to 0.5 part per million, much higher than the less than 50 parts per billion described in the preceding paragraph and higher than expected in the repository. More testing of longer duration will be required to clarify the effects of methane on corrosion.

The waste package is being designed so that the radiolysis will not contribute significantly to container corrosion. A thickness of 8.5 centimeters (3.3 inches) will reduce the radiolysis expected at the container surface to levels where conservative calculations indicate that uniform corrosion enhancement will be insignificant (Anderson, 1985). Test programs are ongoing or planned to verify these assumptions of uniform corrosion and other corrosion modes. In summary, ground-water conditions are not expected to prevent the waste container from reaching its design lifetime because of corrosion.

Natural colloids in ground waters could adsorb radionuclides and promote more rapid transport and release of radionuclides. The presence of natural colloids existing in Grande Ronde Basalt ground water has not been demonstrated. The bulk of previous drilling involves the use of bentonite-based drilling fluids; thus, any colloid sampled from these ground waters was suspect. Consequently, no determination of colloids in Grande Ronde Basalt ground water has been attempted. Unambiguous determination of the presence of natural colloids in ground waters must await large-scale pump tests in rotary-drilled boreholes in and around the reference repository location.

6.3.1.2.9 Potentially adverse condition

"(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength."

The basalt geochemical environment is expected to maintain a high affinity for sorptive radionuclides. Rock strength is not expected to degrade due to existing geochemical processes or conditions. Therefore, it appears likely that this potentially adverse condition is not present at the reference repository location.

Potentially adverse geochemical processes that might enhance radionuclide mobility in the engineered barriers are discussed in Subsection 6.3.1.2.8. With the exception of radiation-induced factors, other factors (e.g., organic content, fluoride content, colloids) could affect radionuclide sorption. Studies are under way to address these concerns (see Subsections 4.1.1.5 and 6.3.1.1.11). With regard to the degradation of rock strength by geochemical processes, the only potentially degrading process is the dissolution of basalt phases (primarily glass) that line the fractures. These dissolution reactions produce secondary minerals that fill fractures and vesicles in basalt. The rate of dissolution is expected to be slow even in the rock zone heated by radiogenic decay of waste radionuclides. The relatively small quantities of secondary minerals in flow interiors (less than 0.3 percent by volume for the Cohassett flow interior) produced over millions of years give evidence for the slow dissolution rate. The clay minerals that constitute the major portion of fracture infilling are not expected to change significantly in character as a result of any geochemical alteration at elevated temperatures.

6.3.1.2.10 Potentially adverse condition

"(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing."

All the evidence supports non-oxidizing geochemical conditions at depth in the reference repository location. Therefore, this potentially adverse condition does not appear to be present at the reference repository location.

Field measurements of Eh in the Grande Ronde Basalt flows range from plus 0.3 to minus 0.2 volt. However, these values are uncertain because of the difficulties involved in the accurate measurement of in situ Eh (Stumm and Morgan, 1981, pp. 490 through 493; Lindberg and Runnells, 1984). Consequently, several indirect methods have been used to obtain additional estimates of Eh values. These methods are based on thermodynamic calculations using reactions among observed solid phases and considering the absence of specific solid phases and (or) dissolved species in the basalt-ground water system, which include the following:

- Existence of iron-bearing secondary phases coating fractures in the basalt (pyrite, nontronite, smectite, and mixed ferrous and ferric oxyhydroxites).
- Absence of naturally occurring secondary hematite.
- Occurrence of sulfide ion coexisting with sulfate, and methane coexisting with carbon dioxide and carbon monoxide.

Estimates of Eh from these couples converge at an Eh of approximately minus 0.4 volt. Additional supporting evidence was obtained by Jantzen (1983) by equilibrating deionized water with basalt at ambient repository temperatures. The low-redox potential (approximately or equal to minus 0.4 volt) was simulated using this approach. A more detailed discussion of evidence for reducing conditions is presented in Subsection 6.3.1.2.2.

6.3.1.2.11 Conclusions on qualifying conditions

The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3). This preliminary conclusion is based on the following factors.

- Naturally occurring alteration phases of basalt are the same as or similar to those expected to form under repository conditions and are highly sorptive for many radionuclides.
- Repository and basalt geochemical environment is reducing and tends to result in low steady-state concentrations and high sorption for most radionuclides significant to repository performance.
- Modeling results indicate that less than 0.001 percent per year of the total radionuclide inventory will dissolve from a repository in basalt.
- Changes in rock strength due to dissolution reactions will be insignificant.

Although these factors support the conclusion that the qualifying condition is met, several uncertainties exist; these include the following:

- Incomplete understanding of the effects of potential complexants (e.g., dissolved organics).
- Incomplete thermodynamic data base for theoretical solubility calculations.
- Incomplete knowledge of the importance of colloids in the basalt geochemical system.
- Incomplete knowledge of the potential effects of radiolysis on radionuclide containment of the engineered barriers.

Experimental and theoretical studies that will address these uncertainties are in progress or planned.

6.3.1.3 Rock characteristics (Section 960.4-2-3)

6.3.1.3.1 Qualifying condition

"The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology."

6.3.1.3.2 Evaluation process

The present and expected rock characteristics of the Cohassett flow and surrounding units are discussed in the following favorable and potentially adverse conditions with respect to compliance with Section 960.4-1 (DOE, 1984a) for radionuclide releases to the accessible environment and 10 CFR 60.113 (NRC, 1985a) for radionuclide release rates from the engineered barrier system. Preliminary postclosure performance assessment (Section 6.4.2) results were used as a basis for defining positions on the favorable and potentially adverse conditions. The performance assessment studies presented in Subsections 6.4.2.4 and 6.4.2.6 evaluated the isolation characteristics of the Cohassett flow and surrounding units for several conceptual models (Clifton, 1986) of the geohydrologic setting. This preliminary analysis suggests that the reference repository location could meet the U.S. Nuclear Regulatory Commission (NRC, 1985a) release-rate performance objective and the U.S. Environmental Protection Agency (EPA, 1985) radionuclide flux release standard.

The discussion of the postclosure rock characteristics condition addresses specific rock mass characteristics that affect waste containment and isolation. The preclosure rock characteristics guideline (e.g., personnel safety, rock opening stability, maintenance, and waste retrievability) is discussed in Subsection 6.3.3.2.

Changes in the physical characteristics of the Cohassett flow are expected to occur due to the excavation of drifts and the drilling of shafts and emplacement boreholes. These physical changes (damaged rock zone) are not expected to extend more than a few meters (feet) beyond the opening. An increase in porosity is expected to occur in the damaged rock zone around the waste-emplacement boreholes that will affect radionuclide-release rates. The estimated rates in Subsection 6.4.2.4 included these changes and are below the limits specified in 10 CFR 60.113 (NRC, 1985a). The cumulative release standard is expected to be met even if radionuclide travel time through all or part of the Cohassett flow interior is neglected (Subsection 6.4.2.6.2). Physical changes in rock characteristics induced by construction, operation, and closure and by interactions with waste, ground water, and engineered components will still allow compliance with the release-rate requirement specified in 10 CFR 60.113 (NRC, 1985a) or the cumulative release requirement specified in Section 960.4-1 (DOE, 1984a).

6.3.1.3.3 Favorable condition

"(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation."

The Cohassett flow could provide a sufficiently thick and laterally extensive host rock to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to assure isolation. Rock damage at the waste package and host rock interface is not expected to prevent compliance with radionuclide-release rate criteria. Also, long ground-water travel times through the Cohassett flow interior may not be essential to meeting overall isolation criteria. However, a limited data base exists regarding the use and performance of the vesicular zone within the Cohassett flow interior. A conservative position has been adopted that this favorable condition is not present, because of uncertainty in the use of the vesicular zone in the Cohassett flow interior for the emplacement of waste.

The lateral extent of the Cohassett flow and intraflow structures is illustrated in the isopach maps shown in Figures 3-11, 3-13, 3-14, and 3-15. Figure 3-14 illustrates that the lateral extent of the flow interior would provide significant lateral flexibility for locating a repository. The current conceptual repository layout requires an 800-hectare (2,000-acre) subsurface facility that can easily be accommodated within a 4,050-hectare (10,000-acre) reference repository location. Beyond the reference repository location boundary, the Cohassett flow is known to be present throughout the Pasco Basin. This distance far exceeds the 5-kilometer (3-mile) horizontal distance to the accessible environment.

To establish the required thickness of the Cohassett flow for repository development, preclosure and postclosure concerns must be taken into consideration. Preliminary performance assessment results in Subsection 6.4.2.4 indicate that expected changes to rock properties at the waste package and host rock interface will not increase predicted radionuclide-release rates to values that exceed requirements of 10 CFR 60.113 (NRC, 1985a). A provision for buffers of unexcavated rock in the flow interior between the emplacement room and the adjacent flow tops is desirable but not required (Fig. 6-5). The buffer at the base of the flow is primarily for preclosure structural integrity, while the buffer above the emplacement room is for structural integrity and waste isolation.

The thickness of the Cohassett flow interior, which is discussed in Subsections 3.2.2.3 and 6.3.3.2.3, has been determined in eight boreholes in and adjacent to the reference repository location and ranges from 62.2 to 75.6 meters (204 to 248 feet). The mean interior thickness from these eight boreholes is 71.7 meters (235 feet). The Cohassett flow interior thickness is greater than 50 meters (165 feet) in the reference repository location (see Fig. 3-14).

To ensure the postclosure isolation of the waste materials, a buffer of 10 meters (33 feet) of undamaged flow interior is to be provided between the emplacement room and the flow top. This buffer restricts the thickness of the flow available for construction. To maintain the 10-meter (33-foot) buffer, the emplacement rooms must be located so that induced fracturing does not penetrate this buffer. Analysis of the initial stress, rock mass strength, thermal loads, and repository opening shapes and sizes (RKE/PB, 1984c) indicate that the thermal-induced fracturing will be within the zone damaged during construction. This damaged rock zone extends approximately 1 to 2 meters (3 to 7 feet) from the excavated opening. This damaged rock will be supported and reinforced by rock bolts and shotcrete during the preclosure period and subsequent deformations in the postclosure period are expected to be limited by backfilling materials. Therefore, for conservativism, this 15-meter (49-foot) postclosure buffer will be provided to account for any potential disturbance above the emplacement room (see Fig. 6-5).

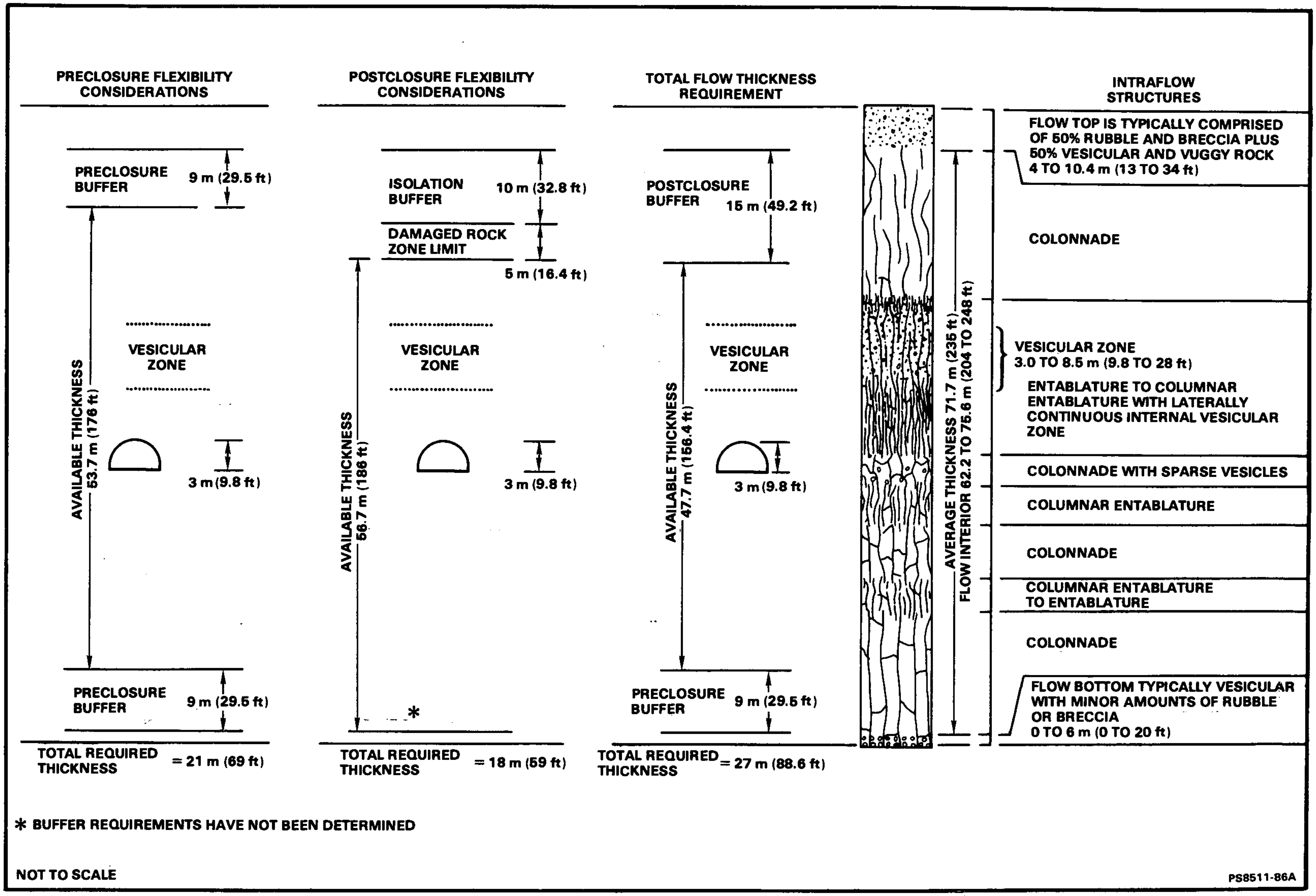


Figure 6-5. Repository emplacement room flexibility of the Cohassett flow.

In the reference repository location, the Cohassett flow interior contains a laterally continuous vesicular zone, ranging in thickness between 3.0 and 8.5 meters (10 and 28 feet) (see Fig. 3-15 and 6-5). The uppermost extent of this vesicular zone is 20 meters (66 feet) below the bottom of the Cohasset flow top. Differences between the intraflow structures in the vesicular zone and a typical flow top indicate that these structures have different origins. Basalt flow tops are typically brecciated, rubbly, and (or) vesicular due to flow emplacement and rapid cooling. The Cohassett vesicular zone is vesicular to vuggy and contains primary fractures, related to a slow cooling process, that are typical for basalt flow interiors. Based on the differences in formational processes, the vesicular zone is expected to be similar hydrologically to the Cohassett flow interior rather than the flow top. Testing of the vesicular zone at four boreholes in and adjacent to the reference repository location yield hydraulic conductivity ranges of 10^{-16} to 10^{-14}, 10^{-16} to 10^{-13}, 10^{-14} to 10^{-12}, and 10^{-9} to 10^{-8} meter per second (10^{-11} to 10^{-9}, 10^{-11} to 10^{-8}, 10^{-9} to 10^{-7}, and 10^{-4} to 10^{-3} foot per day). With one exception, these hydraulic conductivities are typical of the conductivities measured in basalt flow interiors. The exception (10^{-9} to 10^{-8} meter per second (10^{-4} to 10^{-3} foot per day)) is similar to some of the lower conductivities measured in Grande Ronde Basalt flow tops. The reason for this one comparatively high conductivity in the vesicular zone is not understood. However, based on geologic and hydrologic data from the vesicular zone at the other locations, this high hydraulic conductivity may be related to a local feature. Additional investigation of the vesicular zone is warranted before a determination of the utility of the vesicular zone for emplacement of waste can be established. Current repository designs do not require or assume emplacement of waste within the vesicular zone.

The conservative position of not present for this favorable condition relative to the thickness is taken because of the uncertainty of the hydraulic conductivity of the vesicular zone. Future studies will evaluate the hydraulic conductivity of the vesicular zone and, if shown to be comparable to the dense interior, this favorable condition could be present. The remainder of this section describes the thickness requirements expected of the Cohassett flow interior and assumes the vesicular zone is available for excavating the underground facility.

The Cohassett flow interior is approximately 15 times thicker than the required excavation height, which provides flexibility for excavating the emplacement rooms. A buffer of 15 meters (49 feet) has been assumed to be sufficient to ensure that a 10-meter (33-foot) portion of the host rock above the emplacement rooms remains undamaged for postclosure considerations. Also, a buffer of 9 meters (30 feet) has been required below the emplacement rooms to ensure structural stability required for preclosure considerations. Since the Cohassett flow interior in the reference repository location is an average of 71.7 meters (235 feet), 47.7 meters (156.5 feet) remain available to provide for a 3-meter- (10 foot-) high emplacement room opening.

6.3.1.3.4 Favorable condition

"(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components."

This favorable condition is present at the reference repository location due to the low coefficient of thermal expansion of the Cohassett flow basaltic rock in general.

Laboratory testing of intact basalt core samples from the Hanford Site has been conducted to determine the thermal properties of the rock. The results of these tests are presented in Table 6-7. For comparison, generic and specific thermal properties of other rock types are presented in Tables 6-8 and 6-9. These values are for intact rock and may not reflect properties of the rock mass in closely jointed conditions. However, field tests from the Near-Surface Test Facility at the Hanford Site (see Fig. 3-34) indicate good agreement between measured temperature changes in jointed basaltic rock and predicted temperature changes based on laboratory-determined thermal conductivity measurements for intact rock (Huyakorn et al., 1981).

The thermal expansion coefficient for basalt is generally lower than granite, tuff, quartzite, and sandstones and is substantially lower than values for salt. This single characteristic is sufficient to satisfy the favorable condition. The thermal conductivity of basalt is low in comparison with other rock types.

The basalt flow interior is not expected to have sufficient ductility to seal repository-related fractures. Laboratory testing and field observations indicate that basalt deforms in a brittle manner (Bauer et al., 1981, p. 74; Sublette, 1983). Hydrothermal alteration of the basalt in the vicinity of the waste package is expected to fill fractures, resulting in improved host rock isolation characteristics.

Interactions between the host rock and ground water in the vicinity of the waste package are expected to improve the isolation characteristics of the host rock. Hydrothermal alterations could decrease the permeability of the Cohassett flow interior in unfilled fractures by converting basalt glass to secondary minerals (e.g., clays, zeolites). Subsection 6.3.1.6.5 provides further discussion of fracture-filling processes. Further field sampling and subsequent laboratory and field testing at elevated temperatures and pressures would be required to characterize the rock mass thermomechanical behavior and the potential for hydrothermal alteration (see Section 4.1.1).

Table 6-7. Thermal properties of selected flows from the Columbia River Basalt Group at the Hanford Site

Property	Grande Ronde Basalt		Saddle Mountains Basalt
	Cohassett flow	Umtanum flow	Pomona flow
Heat capacity (J/kg-K)			
No. of samples	3	9	26
Regression equation	766 + 0.816T*	862 + 0.586T*	845 + 0.519T*
Standard deviation:			
of y about x	9.33	68.6	64.0
slope	0.0258	0.113	0.0644
Thermal conductivity (W/m-K)			
No. of samples	6	11	30
Mean	1.51	1.71	1.85
Standard deviation	0.152	0.478	0.38
Range	1.31-1.74	1.27-2.46	1.16-2.65
80% confidence interval	1.42-1.60	1.51-1.91	1.76-1.94
Coefficient of thermal expansion ($10^{-6}/^{o}C$)			
No. of samples	2	9	38
Mean	6.02	6.51	6.40
Standard deviation	0.42	0.33	1.16
Range	5.72-6.31	5.93-7.00	4.80-8.73
80% confidence interval	5.11-6.92	6.36-6.67	6.17-6.64

NOTE: To convert J/kg-K to cal/g-^{o}C, multiply by 0.000239; to convert W/m-K to cal/cm-sec-^{o}C, multiply by 0.00239.

Taken from Rockwell Hanford Operations (Rockwell, 1983c, p. 54).

*T = Temperature dependency term is in degrees Celsius over the range of 20 to 200^{o}C (68 to 390^{o}F).

Table 6-8. Thermal properties of selected rock types.

Rock type	Temperature, $^{\circ}C$	Thermal conductivity, W/m-K	Thermal expansion, $10^{-6}/^{\circ}C$
Quartz monzonite[a]	NA	2.1 to 3.4	NA
Salt[b]	40	4.0	NA
Salt[b]	300	2.2	NA
Tuff[c]	90	NA	8.9 ± 1.6
Tuff[d]	NA	2.4	NA
Tuff[d]	NA	1.55	NA
Salt[e]	110	2.08 to 6.11	NA
Granite[e]	NA	1.99 to 2.85	NA
Shale[e]	NA	1.47 to 1.68	NA
Tuff (welded)[e]	NA	1.20 to 1.90	NA
Tuff (unwelded)[e]	NA	0.40 to 0.80	NA
Basalt[e]	NA	1.16 to 1.56	NA
Granites and rhyolites[f]	NA	NA	8 ± 3
Andesites and diorites[f]	NA	NA	7 ± 2
Basalts, gabbros, and diabase[f]	NA	NA	5.4 ± 1
Sandstones[f]	NA	NA	10 ± 2
Quartzites[f]	NA	NA	11
Limestone[f]	NA	NA	8 ± 4
Marble[f]	NA	NA	7 ± 2
Slate[f]	NA	NA	9 ± 1
Tuff[g]	NA	1.7 to 2.6	9 to 12
Granite[h]	NA	2.4 to 2.8	6 to 8
Salt[i]	NA	4.5	40

NOTE: NA = Not available.

To convert W/m-K to cal/cm-sec-$^{\circ}C$, multiply by 0.00239; $^{\circ}F$ equals $^{\circ}C$ minus 32 times 0.56.

[a]Durham (1982, Fig. 3 and 4, pp. 5 and 6).
[b]Morgan (1979, p. 5).
[c]Lappin et al. (1982, p. 31).
[d]Klasi et al. (1982, p. 10).
[e]Wang et al. (1983, Table 3.8, p. 34).
[f]Clark (1966, Table 6-10, p. 94).
[g]Estimated values.
[h]Agapito et al. (1977).
[i]Loken (1983).

Table 6-9. Thermal properties of generic rock types

Temperature, °C	Generic basalt	Generic shale	Generic granite	Generic salt
		Thermal expansion, $10^{-6}/^{o}C$		
Not applicable	5.40	8.10	8.10	40.0
		Thermal conductivity, W/m-K		
0	1.16	1.68	2.85	6.11
50	1.19	1.61	2.70	5.02
100	1.26	1.54	2.56	4.20
150	1.31	1.52	2.44	3.60
200	1.37	1.51	2.34	3.11
300	1.49	1.49	2.15	2.49
400	1.56	1.47	1.94	2.08

NOTE: Taken from U.S. Department of Energy (DOE, 1979, pp. 7.2.17, 7.2.20, 7.2.23, 7.2.26).

To convert W/m-K to cal/cm-sec-°C, mulitiply by 0.00239; °F equals °C minus 32 times 0.56.

6.3.1.3.5 Potentially adverse condition

"(1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation."

This potentially adverse condition is not present at the reference repository location, since engineering measures beyond reasonably available technology for the construction, operation, and closure of a repository are not expected to be required to assure waste containment or isolation. The preclosure rock characteristics guideline (e.g., personnel safety, rock opening stability, maintenance, and waste retrievability) is discussed in Subsection 6.3.3.2.

The preferred waste-emplacement configuration uses short horizontal boreholes (see Subsection 5.1.4.1). This configuration was selected primarily to optimize emplacement room shape with respect to in situ stresses, to minimize disturbance to the Cohassett flow interior, and to optimize the potential for waste retrieval. The emplacement borehole will be lined with packing material, using engineering measures considered within reasonably available technology (see Section 5.1.4). Some design, development, and testing of components may be required.

The waste-emplacement density, pitch, and room spacings must be determined such that the potential for thermal-induced fractures sufficient to impact isolation is low. To impact isolation, these fractures would have to be extensive and intersect zones of high permeability. These aspects are controlled by the design through selection of the waste-emplacement density. Current designs (RKE/PB, 1984b) have an emplacement density of 15.9 watts per square meter (64 kilowatts per acre), which has been estimated to increase the horizontal stress at the repository level from 61.5 to 90 megapascals (8,920 to 13,050 pound-force per square inch). This design indicates that the thermal-induced stress rapidly diminishes with distance from the waste. This suggests that, if a fracture were induced or movement along an existing fracture reactivated, its extension causing penetration above and below the repository horizon would be unlikely. Preliminary performance assessment calculations of ground-water travel times and radionuclide migration through a hypothetical inclined fault intersecting the repository did not appear to change significantly the radionuclide transport compared to a nonfault scenario (DOE, 1982e).

The closure of a repository would require the emplacement of a seal system in the repository shafts, in boreholes drilled from the ground surface, and in the access and ventilation drifts connecting the shafts and emplacement rooms. The shafts provide a direct connection between the underground facility and the accessible environment, or to potentially more hydraulically conductive geologic strata. Thus, limiting ground-water flow to and along the shafts is important in isolating the emplaced waste from the accessible environment.

Based on preliminary analysis (Section 6.4.2), the sealed repository openings do not provide a preferential pathway for radionuclide migration to the accessible environment. This conclusion is based on the assumed performance of the waste package in defining the radionuclide source term for the repository seals and hydraulic properties and hydraulic gradients affecting ground-water flow in the site and repository seals subsystems. The finalization of the designs will be based on further analvsis.

The primary sealing component for shaft, drift, and borehole seals is expected to be a low-permeability backfill material of crushed basalt and clay. This mixture was chosen because, at appropriate packing densities, the clay fills the interconnected voids between the crushed rock aggregate and forms a tight interface with the host rock. This precludes creation of preferential pathways to the accessible environment. Formation of a tight interface is also assisted by the use of a clay material (e.g., bentonite), which has a low permeability and swells on contact with water. The materials selected are naturally occurring in the host environment and, therefore, are expected to be stable. The appropriate mix composition and compaction requirements to achieve the required hydraulic resistance through seal materials and along the interface between seal materials and the host rock will be determined should basalt be recommended for characterization. Seal-emplacement techniques will be demonstrated during site characterization and are not expected to be beyond reasonably available technology.

A zone of fractured rock surrounding the excavated drifts, shafts, and boreholes has the potential to provide a pathway for ground-water flow and radionuclide transport. Blind-hole drilling of the shafts and controlled blasting of the drifts are expected to reduce damage to the host rock. Examination of the hydraulic properties and extent of this damaged rock zone will be carried out during site characterization. This information would be used to determine whether the damaged rock zone needs to be sealed. Such sealing may consist of high-pressure grouting to seal joints and fractures or removal of fractured rock and replacement with backfill or other engineered materials. The selection of techniques and materials would be based on engineering studies and development testing to be conducted during the site-characterization phase.

Preliminary performance assessment analysis indicates that ground-water travel-time requirements could be met without taking credit for the Cohassett flow interior. Excavation methods would be designed to reduce the extent of the damaged rock zone to maintain the integrity of the rock mass as a redundant containment barrier. These engineering measures are within the means of reasonably available technology.

6.3.1.3.6 Potentially adverse condition

"(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation."

The Cohassett flow interior has not been assigned a major role in waste containment or isolation, with the exception of a small portion of the flow needed to meet the radionuclide release-rate requirements from the waste package (Subsection 6.4.2.4 and 6.4.2.6). Brine is not present in Columbia River basalts (Subsection 6.3.1.6). The potential for thermal-induced fracturing is low and hydration and dehydration of mineral components are not expected to affect waste containment or isolation. However, a conservative position has been taken that this potentially adverse condition is present.

<u>Evaluation of thermal-induced fractures</u>

The potential for thermal-induced fractures has been evaluated from thermomechanical and thermohydrological mechanisms. Thermomechanical-induced fractures could develop because of high thermal-induced stress changes around the emplacement hole and storage rooms. Thermohydrological-induced fractures could be induced by thermal expansion of fluids in unconnected cavities.

Stress changes and the dynamic loads imposed during excavation are expected to produce a damaged rock zone around the openings. Damage around the emplacement rooms as a result of excavation is expected to be on the order of 1 to 2 meters (3 to 7 feet), but has been conservatively estimated to be within 5 meters (16 feet). The potential for thermal-induced fracturing that could affect waste emplacement must be evaluated, recognizing the presence of this damage.

Thermomechanical response of basalt in the near field has been calculated with closed-form solutions for circular holes (emplacement holes) and finite-element thermomechanical computer codes for analysis of stress and displacement around the emplacement rooms (RKE/PB, 1984c; Mitchell, 1986). The physical, thermal, and mechanical properties were based on laboratory or field measurements. In situ stresses were calculated from the hydraulic fracturing stress measurements made in the Cohassett flow (Kim et al., 1984b). Rock mass strength estimates were made on laboratory test data for intact basalt, and scaled down to account for the jointing in the basalt flow in the manner demonstrated for granulated marble by Rosengren and Jaeger (1968). The results of these analyses indicate the thermal-induced damage does not extend beyond the construction-damaged zone. Around the waste-emplacement borehole, a smaller destressed zone is expected because of the method of excavation (drilling) and the smaller hole diameter. The damaged rock zone around the emplacement hole has been estimated to be less than 1.3 centimeters (0.5 inch). For a repository in the Cohassett flow, the analysis predicted that thermal-induced fracturing around the emplacement room crown is limited to 21 centimeters (8.3 inches), which is within the damaged zone caused during excavation and within 5 centimeters (2 inches) for the emplacement hole. The effect of construction- and thermal-induced fracturing have been considered in performance assessment (Subsection 6.4.2.5.1).

The principal barriers to radionuclide migration to the accessible environment are (1) low solubility of waste form, (2) slow movement of ground water from the repository to the accessible environment, and (3) sorption by minerals along ground-water flow paths. In addition, the isolation capability of the system is augmented by the hydrologic and sorptive resistance of the undisturbed dense interior basalt (buffer) between the excavated drifts and borehole and the overlying flow top. Thermal fracturing is not expected to penetrate this 5-meter (16.4-foot) buffer, because excavation will not be allowed within the buffer. The 5 meters (16.4 feet) include the damaged rock zone of approximately 1 to 2 meters (3 to 7 feet).

For the conditions used in the calculations by Raymond Kaiser Engineers, Inc. Parsons Brinckerhoff Quade & Douglas, Inc. (RKE/PB, 1984c) and Mitchell (1986), the results indicate that the potential for thermal-induced fracturing is very low. More importantly, however, the calculations suggest that repository thermal loading can be adjusted if it is discovered that thermal effects could become potentially adverse. Another result of the thermomechanical behavior is the potential to decrease the fracture aperture in the far field, above and below the repository. This could potentially result in longer ground-water travel times, diversion of part of the water flux around the repository, or both.

The potential for thermal-induced fractures arising because of the thermal expansion of water and (or) steam generation has been evaluated. This evaluation assumed thermal expansion of water contained in a sealed vesicle and revealed that high fluid pressures could be induced if the host rock were impermeable. However, given that intact basalt has a permeability of approximately 1×10^{-15} meter per second (3.2×10^{-15} foot per second), the pressures generated in the vesicle would dissipate to a nearby hydraulically connected joint. Hence, the potential for thermal-induced fractures from a water-filled vesicle is very low.

Evaluation for the hydration or dehydration of mineral components

The extent to which dehydration and contraction will affect waste isolation will depend on distribution of hydrous minerals in the host rock, temperature rise imposed on the minerals, and water vapor pressure.

The mineral components with the potential for hydration or dehydration are secondary minerals that fill or partially fill fractures, vugs, and vesicles, and replace some interstitial glass in the basalt itself. The dominant secondary minerals in the Grande Ronde Basalt are smectite (clay), clinoptilolite (a zeolite), and silica polymorphs, including quartz, cristobalite, and opal. Less abundant species are celadonite, mordenite, pyrite, chabazite, and calcite. These identifications are based on X-ray diffraction and scanning electron microscopy studies by Benson and Teague (1982) and studies of core from borehole RRL-2 reported by Long and WCC, (1984). Alteration products were identified as either clay, zeolite, or silica in the modal abundance mineralogy study (Long and WCC, 1984, pp. I-112 to I-116). In all Cohassett flow samples, only traces of zeolite or silica were recorded. Zeolite is estimated to be 9 percent of the fracture infill minerals in the Cohassett flow. The clays constitute 5 percent by volume of the Cohassett flow. The remaining 95 percent of the host rock is composed of plagioclase, pyroxene, or mesostasis glass, which is made up of glass, pyroxene, plagioclase, and iron-titanium oxides. Hydrous minerals are not present in the repository horizon in sufficient quantities to cause significant dehydration effects, because the majority of the alteration products are within the basalt matrix. Only 0.10 percent of the total basalt volume made up of fracture-filled secondary minerals (Long and WCC, 1984, p. I-126).

Dehydration reactions involving smectites and clinoptilolite are reversible below 200°C (392°F) (Bish, 1981), and water vapor pressure significantly increases the temperature of dehydration. The dehydration temperature of smectite clays is expected to be between 200 and 270°C

(392 to 518°F) under the hydrostatic pressure conditions expected in the Cohassett flow during the postclosure period (Koster van Groos, 1981). These temperatures are higher than those expected in the vicinity of the repository; therefore, dehydration is not expected, except for local dehydration around the container and in the damaged rock zone. Smyth (1982) indicates that dehydration of clinoptilolite begins at approximately 85°C (185°F). Clinoptilolite comprises only an estimated 0.012 percent of the total Cohassett dense interior (Long and WCC, 1984, p. I-125), so significant changes on joint or node properties are not expected to occur because of clinoptilolite dehydration. The effect of pressure increase on the dehydration temperature of clinoptilolite has not been determined, but is expected to increase the dehydration temperature.

Evaluation of brine migration

Brine is not found in the basalt at the reference repository location, nor is it known to occur in the Columbia River Basalt Group of the Columbia Plateau (Subsection 6.3.1.6).

Other physical, chemical, or radiation-related phenomena

There are no other known physical, chemical, or radiation-related phenomena that are expected to affect adversely the Cohassett flow interior capability to contain or isolate waste. In the discussion of the geochemistry qualifying condition, it was stated that the expected geochemical characteristics of the basalt at the reference repository location potentially represent a favorable aspect of basalt for assuring the safe containment and long-term isolation of nuclear wastes (see Subsection 6.3.1.2.2). In Subsection 6.3.1.2.5, a finding was made that rock temperature increases around a repository are not expected to cause significant changes to the sorptive properties of existing secondary minerals retarding radionuclides. Hydrothermal alteration of basalt glass (mesostasis) results in the formation of highly sorptive clays and zeolites.

In situ rock characteristics must be evaluated further during site characterization to verify the absence of this potentially adverse condition. See Subsection 4.1.1.6.4 for a brief discussion of geomechanical characteristics to be evaluated.

Conclusion

The Cohassett flow interior at the reference repository location is physically and chemically stable. This basalt flow should be minimally affected by expected repository conditions. Approximately 95 percent of the rock is composed of plagioclase, pyroxene, and mesostasis glass, all nonhydrous minerals. The potential for thermal-induced fracturing is considered low and restricted to the immediate vicinity of the waste-emplacement boreholes. No other physical, chemical, or radiation-related phenomena are expected to affect adversely the waste containment or isolation as specified in regulatory requirements (NRC, 1985a; EPA, 1985).

6.3.1.3.7 Potentially adverse condition

"(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions."

The heat generated by the waste is not expected to affect significantly the geologic structure, geochemical and thermal properties, and hydrologic conditions of the host rock so as to decrease its isolation potential.

The lateral extent, thickness, sorptive properties, and permeability of the intraflow characteristics of the host rock and surrounding units are important in assuring waste isolation. For discussions of how these characteristics could be affected by or would bound thermal loading conditions, refer to Subsections 6.3.1.2.5, 6.3.1.3.4, 6.3.1.3.6, 6.3.1.7.3, and 6.3.3.2.8.

A disruptive event would have to occur for the host rock isolation to be decreased significantly by heat generated from the waste. Because credit is not taken for travel time through the Cohassett flow interior, the local thermal-induced fracturing that may occur around the emplacement boreholes or emplacement rooms is not expected to affect isolation adversely. The underground facility will be located within the flow interior with provision for a buffer (see Fig. 6-5) of undamaged dense interior between the excavations and the flow top.

Thermal effects on the geochemical properties of the Cohassett flow are not expected to affect adversely its isolation capabilities (see Subsection 6.3.2.1.5). Hydrothermal alteration of the host rock would produce secondary minerals similar to those lining the basalt fractures. Heating of the host rock is not expected to decrease significantly the sorption properties of the fracture-lining minerals.

6.3.1.3.8 Conclusion on qualifying condition

Evidence does not support a finding that the reference repository location is not likely to meet the postclosure rock characteristics qualifying condition (Level 3). The present and expected characteristics of the host rock and surrounding units are expected to be capable of permitting compliance with radionuclide-release and waste-isolation requirements.

The following factors support the preliminary finding.

- Basalt has a low coefficient of thermal expansion.
- Cohassett flow is thick and laterally extensive, allowing flexibility when selecting the depth, configuration, and location of the underground facility.
- Occurrence of a vesicular zone presents some uncertainty about the hydraulic conductivity of this feature within the Cohassett flow interior. Although the conductivity is not expected to be significantly different than the flow interior, only a limited data base is available.
- Rock conditions at the reference repository location do not require engineering measures beyond reasonably available technology to assure waste containment or isolation.
- Physical, chemical, or radiation-related phenomena in basalt at the reference repository location are not expected to affect waste containment or isolation as specified in regulatory requirements (NRC, 1985a; EPA, 1985).
- Preliminary performance studies indicate a high probability that the reference repository location could satisfy all U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency isolation requirements (NRC, 1985a; EPA, 1985; Section 6.4.2).
- Creation of extensive thermal-induced fractures would be prevented by limiting the thermal load per hectare (acre).

The above factors are based on a limited data base, empirical analyses, technical judgments, and preliminary performance assessment-modeling results. The uncertainties (e.g., the influence of the Cohassett flow vesicular zone on host rock flexibility) associated with the preliminary finding on this qualifying condition will be addressed by in situ testing should the reference repository location be recommended for site characterization.

6.3.1.4 Climatic changes (Section 960.4-2-4)

6.3.1.4.1 Qualifying condition

"The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting."

6.3.1.4.2 Evaluation process

The paleoclimatic record indicates the Pasco Basin has been the site of proglacial to interglacial climatic settings during the Quaternary Period. Factors contributing to climatic change leading to global mid-latitude glaciation are atmospheric circulation, air and sea interactions, variations in atmospheric carbon dioxide, explosive volcanic activity, and solar variability. The most widely supported forcing mechanism for climatic change is attributed to changes in the Earth and Sun geometry (i.e., the Milankovitch hypothesis; see Imbrie and Imbrie, 1980). Several climatic simulation models have been designed to assess the effects of future glaciation on the Hanford Site (Stottlemyre et al., 1981; Petrie et al., 1981; Craig et al., 1983). Isotope geochemistry and paleomagnetic data indicate that major worldwide glaciations have occurred at periods of approximately 100,000 years for at least the last 800,000 years (Table 6-10).

Evidence from deep sea cores (CLIMAP, 1984, p. 216) suggests that the last interglacial interval (125,000 to 118,000 years before present) was extremely similar to the present climate. The paleoclimatic record also indicates several temporary ice retreats (interstades) may occur with each major glaciation. Glacial cycles are usually characterized by long periods of ice buildup before a glacial maximum is reached, then sudden termination, followed by an interstadial or interglacial interval. Interglacial intervals, however, represent approximately 10 percent of the total glacial-interglacial cycle (Barry, 1983, p. 394).

Potentially adverse effects of future climatic changes include erosion (Subsection 6.3.1.5) or increased runoff and ground-water recharge as a result of seasonal proglacial meltwater or catastrophic release of floodwaters from ice-dammed lakes associated with another glacial period. Floodwaters were released several times during the Pleistocene, and subsequently dammed behind the hydraulic constriction in the Horse Heaven Hills at Wallula Gap, causing short-lived flooding in the Pasco Basin (Fig. 6-6) (see Section 3.2.2). The Pleistocene floods are also referred to as Bretz, Spokane, or Missoula floods. Since the end of the Pleistocene (10,000 years before present), the surface of the Pasco Basin has changed at a slow rate. Thus, geomorphic and hydrologic conditions are not expected to affect adversely the reference repository location during the present interglacial period.

Results from palynological investigations conducted north of the reference repository location indicate that the early postglacial period, 13,000 to 10,000 years ago, was cooler and moister than today (Mack et al., 1976, 1978c; Nickmann, 1979, p. iii; Nickmann and Leopold, 1980, p. 14). This evidence is supported by rockfall frequencies in caves, deposition of eolian sediments, buildup of organic debris (Fryxell, 1964), and rates of accumulation of fanglomerates due to presumably greater runoff (Brown, 1970, p. 29).

Table 6-10. Age of glacial terminations--summary of published estimates[a]

Termination	Broecker and Van Donk (1970)	Kukla[b] (1970)	Shackleton and Opdyke (1973)	Kukla[b] (1975)	Ruddiman and McIntyre (1976)	Hays et al. (1976)	Average (10^3)
I	11,000	10,500	13,000	11,000	13,500	10,000	11.5 $^{-1}_{+2}$
II	127,000	128,000	128,000	128,000	127,000	127,000	128.0 $^{-1}_{+0}$
III	225,000	243,000	251,000	245,000	220,000	247,000	240.0 $^{-20}_{+10}$
IV	300,000	333,000	347,000	335,000	315,000	336,000	330.0 $^{-30}_{+20}$
V	380,000	370,000	440,000	415,000	380,000	425,000	400.0 $^{-30}_{+40}$
VI	(c)	485,000	502,000	480,000	455,000	(c)	480.0 $^{-25}_{+20}$
VII	(c)	600,000	592,000	575,000	515,000	(c)	570.0 $^{-55}_{+30}$
VIII	(c)	(c)	647,000	635,000	605,000	(c)	630.0 $^{-25}_{+20}$
IX	(c)	726,000	706,000	700,000	(c)	(c)	710.0 $^{-10}_{+15}$
X	(c)	845,000	782,000	(c)	(c)	(c)	810.0 $^{-30}_{+35}$

[a]Modified from Stottlemyre et al. (1981, p. 48); data on this table compiled by G. K. Kukla.
[b]Published in Stottlemyre et al. (1981).
[c]No glaciation period identified.

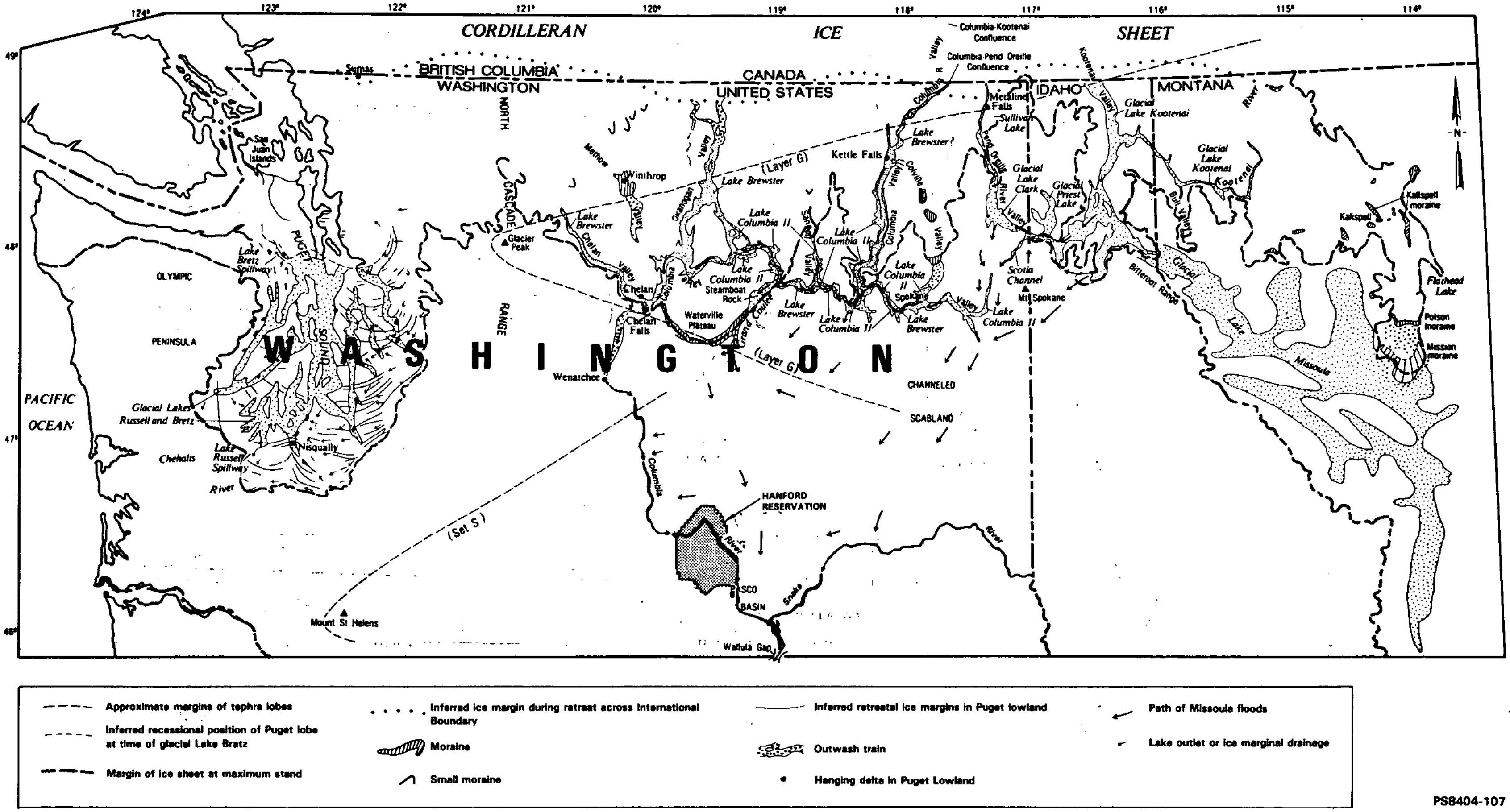


Figure 6-6. Inferred generalized margin of Cordilleran ice sheet and glacial lakes approximately 12,000 plus or minus 1,000 years before present (after Waitt and Thorson, 1983, pp. 62 and 63).

The change to a warmer, drier climate occurred approximately 8,000 years ago. The relative aridity has been deduced from changes in plant species (Mack et al., 1976, 1978a, 1978b, 1978c; Nickmann, 1979, p. 53; Nickmann and Leopold, 1980, p. 15; Hansen, 1947), lessened frost activity (Fryxell, 1964), increased wind deposits (ERDA, 1975, p. II.3-10; Brown, 1970, p. 31), changes in fauna (Brown, 1970, p. 31; Frison, 1975; Knudson, 1980), changes in mountain glacier size and location (Porter, 1977), and changes in patterned ground distribution (Mack et al., 1976). The warm, dry climate that appears to have developed approximately 8,000 years ago lasted approximately 4,000 years. Many of the mammal species that inhabited the Columbia Plateau during this 4,000-year period migrated or became extinct. The effective precipitation, which supported the extensive grassland of the region, decreased, resulting in changes in vegetation distribution (Mack et al., 1976, 1978c; Nickmann, 1979, p. 54). Active sand dunes were formed on the Hanford Site and at other locations throughout the eastern portion of the State of Washington (ERDA, 1975, p. II.3-10). Some of these now-stabilized dunes contain ash beds from the Mount Mazama eruption 6,700 years ago in southern Oregon (Fryxell, 1965). This evidence indicates that the dunes were formed 6,000 to 7,000 years ago (ERDA, 1975, p. II.3-10).

A later climatic change to conditions slightly cooler and moister than today is thought to have occurred roughly between 3,000 or 4,000 years and 1,500 years before present. This change is controversial, since palynological evidence is present at some sites but absent at others (Mack et al., 1978a). The modern climate appears to have prevailed in the region since 1,500 years ago (Mack et al., 1978c).

Geologic data suggest that little runoff has occurred since late-Pleistocene or early-Holocene times. Based on topographic arguments and geologic information, Kukla (1979, pp. XIII-1 through XIII-8) suggested that the long-term change in mean annual precipitation since the last glacial episode is probably within the range of recent year to year variability. The annual precipitation at the Hanford Site and vicinity has averaged 16.1 centimeters (6.3 inches) and, since 1913, has varied between 7.6 and 29.1 centimeters (3 and 11.5 inches) (Stone et al., 1983, p. IV-2; see Section 3.4.3). Mean annual precipitation since 13,000 years ago is projected to be within a factor of 2 of the present mean annual precipitation of approximately 16 centimeters (6 inches) (Stottlemyre et al., 1981).

Alpine glaciers in the Cascade Range were greatly expanded relative to their present size during the last major advance of continental ice sheets. However, the closest advance of these continental ice sheets to the Hanford Site is marked by the Withrow terminal moraine, approximately 130 kilometers (81 miles) north of the reference repository location. Investigation by Porter (1977) of the glaciation thresholds at the maximum ice advance of the last glacial interval supports the view that the accumulated precipitation for the season during the ice advance was probably no more than 30 percent greater than present values.

6.3.1.4.3 Favorable condition

"(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation."

Climatic conditions in the reference repository location and surrounding area are expected to remain essentially unchanged over the next 100,000 years, except for a colder, drier climate associated with a postulated glacial advance. The surface-water systems associated with preglacial and interglacial periods are not expected to change significantly. Changes to the surface-water system from catastrophic flooding are expected to be transient. Over the next 100,000 years, changes to the surface-water system are not expected to affect the deep ground-water flow system that is important to waste isolation. Therefore, this favorable condition appears to be present at the reference repository location.

The climate of the Pasco Basin has remained arid to semiarid for at least the last 3 million years, as indicated by the presence of calcic paleosols in the upper unit of the Ringold Formation and younger strata. The overall regional precipitation pattern, controlled primarily by the Cascade Range, is not likely to change significantly over the next 100,000 years.

Significant changes in regional ground-water flow are unlikely to occur as a result of diversion of the Columbia River within the Pasco Basin over the next 100,000 years. No evidence exists that the Columbia River has occupied the Cold Creek syncline since the last catastrophic flood (13,000 years ago). Paleochannels within the Cold Creek syncline, interpreted as former channels of the Columbia River by Newcomb et al. (1972), have been reinterpreted as catastrophic flood channels (Fecht, 1978). While future glacial activity potentially could cause proglacial aggradation (outwash plain) within the Pasco Basin, a rise in base level of approximately 25 meters (80 feet) would be required to divert the Columbia River from its entrenched position in the Wahluke and Pasco synclines, through the saddle between Gable Mountain and Gable Butte, and into the Cold Creek syncline. The potential is low for such a future diversion. The maximum amount of aggradation associated with future glacial advances is not known, but will be addressed as part of the climatic modeling performed during site characterization, if the site were recommended for such activity.

Another scenario proposed for channel diversion, landslide blockage of the Columbia River, is considered unlikely. According to a study by Hays and Schuster (1984), landsliding was inactive during the period between the last catastrophic flood and the time irrigation began in the late 1800's. Since that time, irrigation-induced landslides have occurred frequently but have not traveled more than a few hundred meters (feet), and toes of landslides have not exceeded 30 meters (100 feet) in thickness. A landslide would have to travel almost 5 kilometers (3 miles) from the White Bluffs and be 25 meters (80 feet) thick at the toe to divert the Columbia River through the gap between Gable Mountain and Gable Butte. No evidence suggests landslides off the White Bluffs have traveled this distance or maintained such a thickness, thus no evidence suggests that landslides would block the Columbia River in the future.

Climates during glaciation are reported to be colder and drier (Barry, 1983); thus, increased runoff and (or) erosion within the Pasco Basin are not expected during periods of glacial advance. Large accumulations of wind-blown sediment (loess) deposited in the eastern portion of the State of Washington during the Pleistocene are believed to reflect the overall cold and dry periglacial conditions that existed along glacial margins.

Melting of glacial ice during periods of interstadial ice retreat may result in increased runoff and glaciofluvial channeling. However, potential erosion within the Pasco Basin in the near future is expected to be limited to depths at or above temporary base levels at Wallula Gap. Over the long term, the potential for fluvial or glaciofluvial incision is ultimately controlled by sea level. Climatically induced changes in base level over the next 1 million years are most likely to come about through future global glaciation. Conceivably, based on worldwide Pleistocene sea-level fluctuations, regional base level could drop from approximately 100 to as much as 250 meters (300 to 820 feet) below present sea level during the next glacial advance (WCC, 1980). The Cohassett flow in the reference repository location is generally greater than 645 meters (2,117 feet) below sea level. Fluvial headward erosion from such a drop in sea level could incise no closer than 440 meters (1,443 feet) above the Cohassett flow if the maximum drop in sea level were to occur (Subsection 6.3.1.5).

The geomorphic effects of catastrophic flooding are considered to be negligible, since the net effect within the reference repository location would be sediment aggradation. Relatively minor cut-and-fill sequences have been observed within and around the reference repository location, but none have incised into underlying deposits more than several meters (feet). The main channels for Pleistocene catastrophic floods have been located north and east of the reference repository location (Tallman et al., 1979, pp. 44 through 48; Myers, Price et al., 1979, p. III-66). The topographic control on the position of these channels (basalt ridges) would be expected to remain the same for potential future floods and, therefore, major incision within the reference repository location is not likely. Approximately 175 to 200 meters (575 to 650 feet) of sediments overlie the top of the basalt in the reference repository location. Less than 50 meters (164 feet) are flood deposits; the remainder of the sediments belongs to the Miocene-Pliocene Ringold Formation and the Plio-Pleistocene unit (see Section 3.2.2). On the basis of borehole data, the Ringold Formation has not been eroded in the reference repository location below an elevation of 135 meters (444 feet) during the Quaternary Period (Bjornstad, 1984; see Fig. 3-18).

On the basis of the paleoclimate model of Craig et al. (1983, Fig. 21), two major ice advances are predicted for the next 100,000 years. According to the Craig et al. (1983) model, the first major glacial advance is predicted to begin approximately 15,000 years from now and to continue for approximately 10,000 years before retreating. This advance, however, is not expected to extend south far enough to cause ice damming or subsequent catastrophic flooding (Craig et al., 1983, Fig. 21). A second major advance is predicted to begin in approximately 35,000 years and to reach a maximum after another 25,000 years (or 60,000 years from now). Ice dams created by this advance could cause catastrophic floods. The impact of catastrophic flooding on the deep ground-water flow system or the potential for induced seismicity that could affect ground-water flow paths has not been addressed in detail. The short duration of such floods (estimated to be weeks or less; Baker, 1973, pp. 20 through 22), however, suggests that the effects on the portion of the deep ground-water flow system important to waste isolation would be minor.

6.3.1.4.4 Favorable condition

"(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period."

Although an arid climate has prevailed east of the Cascade Range over the past 3 million years, climatic changes have produced Pleistocene glaciers that impinged on the northern portions of the Columbia Plateau (geologic setting). The erosion associated with glacial advances must have had an effect on the hydrologic system of the plateau; however, the effects have not been quantified. Therefore, it would appear that this favorable condition may not be present.

There is no evidence to suggest that glaciers have ever reached the central Columbia Plateau or the reference repository location. However, glaciers and proglacial meltwaters have modified the land surface of portions of the Columbia Plateau. It is assumed that these Quaternary Period glacial and glacial-related events had an effect on the hydrologic system of the Columbia Plateau. The effect on the hydrologic system will be addressed during site characterization, if the site was selected for characterization.

6.3.1.4.5 Potentially adverse condition

"(1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock."

The underground facilities of a repository in basalt would be in a saturated host rock. Therefore, this potentially adverse condition does not apply to the reference repository location and no further analysis is required.

6.3.1.4.6 Potentially adverse condition

"(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment."

The climate of the Hanford Site region is not expected to change significantly over the next 10,000 years. Thus, the ground-water flow system is expected to remain relatively unaffected. Therefore, the evidence does not support a finding that this potentially adverse condition is present at the reference repository location.

Proglacial catastrophic flooding, similar to the Pleistocene flooding events, appears to be the most probable disruptive scenario associated with climatic changes that could affect the hydrologic system. However, there is little chance of significant renewed glaciation in the State of Washington in the next 10 000 years (see Subsection 6.3.1.4.3). In addition, ground-water impacts from proglacial flooding are likely to be limited to localized recharge increases to the shallow ground-water flow system and increases in stream runoff. The short, transient nature of catastrophic floods (i.e., weeks or less) is such that significant long-term adverse effects at the repository depth are not expected.

6.3.1.4.7 Conclusion on qualifying condition

A final conclusion on the qualifying condition for climatic changes cannot be made based on available data. However, the evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3).

Among the potentially adverse effects associated with climatic change are increases in surface runoff, leading to erosion or changes in ground-water flow. Extreme erosion is not likely over the next 100,000 years (Subsection 6.3.1.5). Increases in runoff are likely to occur over the next 100,000 years, either through catastrophic floods or seasonally by proglacial streams. Changes in the deep ground-water flow system are expected to be small, since the effects of catastrophic floods and seasonal proglacial streams on the ground-water system are expected to be local, transient, and shallow (see Subsection 6.3.1.4.6).

6.3.1.5 Erosion (Section 960.4-2-5)

6.3.1.5.1 Qualifying condition

"The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will "not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period."

6.3.1.5.2 Evaluation process

In evaluating the potential for future disruption of a repository through erosion, the effects of past and present erosional processes must be identified. A variety of surficial processes has been operating since a major incision of the Ringold Formation took place possibly 2 million years ago (Fecht et al., 1985). A remnant of the Ringold Formation paleosurface is preserved at an elevation of approximately 275 meters (902 feet) along the White Bluffs approximately 16 kilometers (10 miles) northeast of the reference repository location.

In the reference repository location, incision of the Ringold Formation paleosurface and lateral planation produced a younger paleosurface (see Fig. 3-18) that is preserved south of the Umtanum Ridge bar (see Fig. 3-5). This buried surface (see Fig. 3-18), represented by the erosional top of the Ringold Formation, trends parallel to the present Cold Creek Valley, suggesting an ancestral Cold Creek origin. North and east of Umtanum Ridge bar, the younger paleosurface was eroded, apparently by Pleistocene catastrophic floods. Maximum incision occurred in the southeastern portion of the reference repository location (see Fig. 3-18), where the Ringold Formation is eroded to an elevation of less than 135 meters (444 feet) above mean sea level.

Partial infilling of the ancestral Cold Creek Valley with locally derived alluvium occurred before and perhaps between periods of catastrophic flood deposition during the Pleistocene. As a result of catastrophic floods entering the Pasco Basin from the north, a major geomorphic feature, the Umtanum Ridge bar, developed in the reference repository location (see Section 3.2.1). This streamlined, compound flood bar accumulated south of Umtanum Ridge and on the south flank of a northwest-trending flood channel (see Fig. 3-5). Flood channels in the Pasco Basin eroded to an elevation of 83 meters (272 feet) northeast of the reference repository location between Gable Mountain and Gable Butte (Fecht, 1978) and approximately 50 meters (164 feet) at Wallula Gap (WCC, 1980), the outlet for floodwaters from the Pasco Basin. The Umtanum Ridge bar acted to confine erosion to the north, while causing net deposition on the downstream (south) side. As a result, the Cold Creek paleosurface south of Umtanum Ridge bar was preserved under the accumulating cover of slack-water flood deposits.

Since the last catastrophic flood around 13,000 years before present, the reference repository location surface has undergone only minor local reworking through fluvial and eolian processes.

The potential for incision at the reference repository location in the near future is estimated to be less than 50 meters (164 feet) in elevation defined by local base-level control at Wallula Gap 80 kilometers (50 miles) southeast of the reference repository location. However, fluvial processes in Cold Creek Valley, at the western boundary of the reference repository location, have been only intermittently active (Skaggs and Walters, 1981) since the last major flood event, approximately 13,000 years before present. The next catastrophic flood is not expected to occur during at least the next 60,000 years (Craig et al., 1983). Therefore, only minimal incision (a few meters (feet) or less) in the Cold Creek Valley in and adjacent to the reference repository location is expected in the near future.

The potential for incision over the long term is ultimately controlled by sea level. Changes in base level over the next 1 million years are likely to come about through glacio-eustatic changes in sea level. Conceivably, based on Pleistocene sea-level fluctuations, regional base level could drop approximately 100 meters (300 feet) to as much as 250 meters (820 feet) below present sea level (WCC, 1980). The Cohassett flow in the reference repository location is generally greater than 645 meters (2,117 feet) below sea level. In the unlikely case of headward erosion from such a drop in sea level advancing to the site, erosion could proceed no closer than 440 meters (1,443 feet) above the Cohassett flow. Furthermore, the tectonic setting of the reference repository location, located within a structural basin subsiding since at least the early to middle Miocene time (16.5 million years before present) (Caggiano and Duncan, 1983), is such that depths to a proposed repository should increase with time.

Significant increases in recharge to the deep ground-water flow system are not expected over the next 10,000 years as a result of present or future surface exposures around the Columbia Plateau or future catastrophic flooding. Recharge of aquifers in the lower Wanapum and Grande Ronde Basalts is believed to be controlled by infiltration along the margins of the Columbia Plateau where these units are extensively exposed. From the margins of the plateau, the confined ground water is believed to move more or less laterally toward the topographically low Pasco Basin (see Section 2.1.4). Recharge of the deep ground-water flow system around the margins of the Columbia Plateau could occur through additional erosion or an increase in infiltration during future catastrophic flooding. The short, transient nature of the flooding would severely limit infiltration, and erosion is not expected to proceed much lower than present coulee depths.

Unlike the deep ground-water flow system, the unconfined Saddle Mountains Basalt aquifers and possibly the upper Wanapum Basalt aquifer are recharged locally, probably from infiltration of precipitation and runoff within and along the margins of the Pasco Basin (see Section 3.3.2). The rates of erosion within the Pasco Basin during the Quaternary Period, do not suggest incision to or perturbation of the deep ground-water flow system would occur.

Future incision of basalt bedrock conceivably could result in increased infiltration and recharge of confined aquifers in the basalt. Incisement into the bedrock surface is ongoing in the basaltic ridges of the Columbia Plateau and Pasco Basin above areas of deposition by catastrophic floods. However, based on present and projected rates of degradation described below, the increased exposure could affect the uppermost (local) confined aquifers, but is not expected to affect the deeper, regional ground-water system.

The rate of degradation is a function of relative tectonic uplift and climate. Rates of tectonic uplift have been determined for the Miocene and projected to the present based on thinning and pinch out of basalt flows over anticlinal ridges. Based on estimates of long-term rates of tectonic deformation by Woodward-Clyde Consultants (WCC, 1980, p. 58) and Reidel (1984, p. 942), incision due to tectonic uplift surrounding the Pasco Basin should not exceed 40 centimeters (16 inches) over the next 10,000 years.

Climate also controls rates of degradation. Calculated on the basis of dissolved and suspended sediment loads, the maximum long-term rate of denudation through normal degradational processes, with probable future changes in temperature and (or) precipitation considered, should not exceed 30 to 50 centimeters (12 to 20 inches) per 10,000 years in lowland areas of the Pasco Basin (WCC, 1980, p. 78). Rates of denudation increase with relief, however, so that larger mountainous areas may degrade up to an order of magnitude faster than lowland areas (WCC, 1980, p. 74). Small areas of high relief around the Pasco Basin and the Columbia Plateau, then, could experience up to 3 to 5 meters (10 to 16 feet) of incision over the next 10,000 years locally due to chemical and mechanical weathering. Assuming that degradation could keep pace with tectonic uplift and climatic change, the maximum amount of incision expected over the next 10,000 years should not exceed approximately 4 to 6 meters (13 to 20 feet) locally in upland areas.

Short-term rates of erosion and infiltration due to catastrophic flooding around the margins of the Columbia Plateau are not expected to affect waste isolation, although some uncertainty exists in the conclusion. At present it is not known how much incision might be associated with future catastrophic floods on the Channeled Scablands, but the short, transient nature of the floods (weeks or less) suggests that there would be insufficient time to allow significant infiltration into the deep ground-water flow system.

6.3.1.5.3 Favorable condition

"(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface."

This favorable condition is present at the reference repository location, because site conditions permit emplacement of waste at a depth of greater than 300 meters (984 feet). The depth to the Cohassett flow top in the reference repository location is 869 to 943 meters (2,850 to 3,093 feet) below ground surface (see Subsection 3.2.2.3).

6.3.1.5.4 Favorable condition

"(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment."

This favorable condition appears to be present at the reference repository location, since there is little, if any, chance of erosion leading to releases of radionuclides to the accessible environment over the next 10,000 years. This preliminary conclusion is based on an estimate of erosional relief on the Ringold Formation and on the geomorphic control that sea level has on limiting depth of erosion as described in Subsection 6.3.1.5.2.

The top of the Ringold Formation, along the White Bluffs 16 kilometers (10 miles) northeast of the reference repository location, represents the level of the ancestral Columbia River in the Pasco Basin approximately 3 million years ago. The maximum relief on the eroded Ringold Formation surface represents the maximum amount of incision that could have taken place during the Quaternary Period. The maximum relief for the top of the Ringold Formation surface between the reference repository location and the White Bluffs is 135 meters (444 feet). Depth to the Cohassett flow in the reference repository location is 869 to 943 meters (2,850 to 3,093 feet) below the ground surface. Therefore, since approximately 3 million years ago, maximum incision in the reference repository location has been equivalent to approximately 25 percent of the depth to the Cohassett flow. Erosion in the reference repository location during the last 3 million years has occurred within the sediments overlying the basalts.

Because depth of erosion is geomorphically controlled by base level, future incision is limited to depths above minimum sea level. Past glacioeustatic sea levels have dropped as low as 250 meters (820 feet) below the present levels during the Pleistocene. Using this value as an ultimate base level, erosion at the reference repository location could proceed no farther than 440 meters (1,443 feet) above the Cohassett flow. Therefore, since erosion can proceed no farther than 440 meters (1,443 feet) above the Cohassett flow, it appears that there is less than one chance in 10,000 over the next 10,000 years that erosion leading to the releases of radionuclides to the accessible environment could occur.

6.3.1.5.5 Favorable condition

"(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure."

This favorable condition appears present at the reference repository location, since waste is not expected to be exhumed during the first 1 million years after repository closure.

The depth of the Cohassett flow and the geologic setting of the reference repository location are such that waste exhumation would not be expected to occur during the first 1 million years after repository closure. Waste exhumation through erosion is not likely, since the Ringold Formation surface within the reference repository location has not been eroded below an elevation of 135 meters (444 feet) over the last 3 million years. The Cohassett flow is 869 to 943 meters (2,850 to 3,093 feet) below ground surface or at an elevation of minus 645 meters (minus 2,117 feet). The likely mechanisms for erosion to this depth are through tectonic uplift of the repository area or a drastic glacio-eustatic lowering of sea level. However, based on the past geologic setting (see Subsection 6.3.1.5.2), neither of these scenarios is expected, especially considering that the site is located in a structural basin subsiding since at least the early to middle Miocene (16.5 million years ago).

6.3.1.5.6 Potentially adverse condition

"(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period."

The reference repository location does not show evidence of extreme erosion during the Quaternary Period. Therefore, this potentially adverse condition is not present at the reference repository location.

The present site has not undergone extreme erosion during the Quaternary Period and is not expected to do so in the foreseeable future. Brief episodes of Pleistocene catastrophic flooding have carved the Channeled Scablands of the Columbia Plateau, but these scablands are not considered the product of extreme erosion. This interpretation is based on the fact that erosion of coulees and channelways is relatively shallow (up to approximately 200 meters (600 feet)) when compared to a proposed repository depth of 869 to 943 meters (2,850 to 3,093 feet) below the ground surface of the reference repository location. The net effect of these floods on the reference repository location has been depositional, because of the protection provided by Umtanum Ridge and the Umtanum Ridge bar (see Fig. 3-5). Assuming a similar source and mechanics of flooding, future catastrophic floods should follow the same coulees and channelways through the Channeled Scablands and aggrade sediments at the reference repository location.

A period of incision that occurred following deposition of the Ringold Formation is bracketed between approximately 3 and 0.9 million years before present, the respective ages of the youngest Ringold deposits on the White Bluffs and of basalt from Haystack Butte (Kienle and Newcomb, 1973). Fecht et al. (1985) suggest the incision occurred approximately 2 million years ago and the incision of the Ringold Formation in the Pasco Basin reflects base-level changes in the area of the present-day Columbia River Gorge. Extrusion of Haystack Butte lava, which occurred approximately 130 kilometers (80 miles) southwest of the reference repository location, extended to near the present river level in the Columbia River Gorge. This indicates that by at least 900,000 years ago and probably 2 million years ago, the major period of incision (as much as 150 meters (500 feet)) had ceased.

The cause(s) of post-Ringold incision is not well understood. Fecht et al. (1985) suggest that downstream changes in base level are due to waning Cascade volcanism in the vicinity of the present-day Columbia River Gorge. Future incision of this type is not expected over the life of the repository.

6.3.1.5.7 Potentially adverse condition

"(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste."

This potentially adverse condition is not present at the reference repository location. The nature and rates of geomorphic processes in the Columbia Plateau are not expected to affect the ability of a repository to isolate waste for 10,000 years after closure.

The only geomorphic process to affect adversely the reference repository location would be exhumation through incision to the Cohassett flow (869 to 943 meters (2,850 to 3,093 feet) below the ground surface). This is not considered possible, based on any combination of geologic, climatic, or tectonic processes that have operated during the Quaternary Period (see Subsections 6.3.1.5.2 and 6.3.1.5.5).

6.3.1.5.8 Disqualifying condition

"The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface."

The depth of the Cohassett flow is 869 to 943 meters (2,850 to 3,093 feet) below the ground surface in the reference repository location. Potential erosion scenarios indicate that this depth is more than sufficient to maintain over 440 meters (1,443 feet) between the ground surface and a repository. Therefore, the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2). Little or no uncertainty is present in making this determination.

The Cohassett flow is located at 869 to 943 meters (2,850 to 3,093 feet) below the ground surface of the reference repository location (see Section 3.2.2). The Cohassett flow depth far exceeds the 200-meter

(650-foot) depth contained in the disqualifying condition, even considering a maximum erosion scenario of a 250-meter (820-foot) reduction of sea level associated with glacio-eustatic changes, and the unlikely case of headward erosion advancing to the site from such a drop in sea level. Erosion is not expected to proceed lower than 440 meters (1,443 feet) above the Cohassett flow.

6.3.1.5.9 Conclusion on qualifying condition

The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition (Level 4). The potential for erosional processes leading to radionuclide releases is not considered possible, based on available data on past and present climatic, tectonic, and geomorphic conditions during the Quaternary Period (see Subsection 6.3.1.5.2). This finding is based on the following factors.

- Depths to the Cohassett flow in the reference repository location that exceed potential future base levels.
- Future tectonic movements should result in relative lowering of a repository.
- Continued net deposition south of Umtanum Ridge and the Umtanum Ridge bar is expected with future catastrophic floods.
- Erosion by future catastrophic floods in the Channeled Scablands north of the Pasco Basin that is not expected to affect the deep ground-water flow system at the reference repository location due to the short, transient nature and shallow erosion associated with these floods. Erosion induced by tectonic uplift and (or) through normal, long-term denudation processes over the next 10,000 years is not expected to exceed more than several meters (feet) and, therefore, should not adversely affect the deep ground-water flow system.

6.3.1.6 Dissolution (Section 960.4-2-6)

6.3.1.6.1 Qualifying condition

"The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified."

6.3.1.6.2 Evaluation process

Rocks of the Columbia River Basalt Group and intercalated Ellensburg Formation are generally not subject to dissolution. Dissolution features or dissolution fronts have not been found, nor are such features expected to be found in the reference repository location. Investigations have shown that hydrothermal reactions occur along cooling joints where dissolution of basalt glass has resulted in precipitation of secondary minerals, including iron smectite, zeolites, and cristobalite (see Section 6.3.1.2). However, only a very small percentage of the rock is expected to undergo these reactions. Dissolution will not significantly decrease rock strength or increase rock permeability at the reference repository location.

6.3.1.6.3 Favorable condition

"No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period."

This favorable condition is present for the basalts at the reference repository location. Significant dissolution does not occur in a basalt geologic medium (Subsection 6.3.1.6.5).

6.3.1.6.4 Potentially adverse condition

"Evidence of significant dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of water isolation could occur."

This potentially adverse condition is not present in the Columbia River Basalt Group, since significant dissolution does not occur in a basaltic medium (Subsection 6.3.1.6.5).

6.3.1.6.5 Disqualifying condition

"The site shall be <u>disqualified</u> if it is likely that, during the first 10,000 years after closure, active dissolution as predicted on the basis of the geologic record, would result in a loss of waste isolation."

Active dissolution fronts do not occur in basalt. Therefore, the evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 2). Little or no uncertainty is involved in meeting this determination. However, some minor dissolution in fractures and vesicles could occur in basalt.

Chemical reactions of the basalt in the presence of heat and water generally lead to the dissolution of some minerals (primary minerals) found in the fractures and porous flow-top portions of the basalt. This dissolution is coupled with the precipitation of secondary minerals. Evidence indicates that the result of these reactions is a net decrease in the porosity and fracture permeability of the basalt (DOE, 1982e, pp. 6.4-1 through 6.4-14). The primary and secondary minerals of the deep geohydrologic system in and around the reference repository location are relatively insoluble. No significant dissolution is expected to occur within the deep geohydrologic system in and around the reference repository location.

The basalts in and around the reference repository location have been extensively studied (see Sections 2.1.1 and 3.2.2). Evidence indicates that the Columbia River Basalt Group was erupted as lava flows 6 to 17 million years ago. As each flow was emplaced, a flow top developed, consisting of vesicles, rubble, and breccia. After emplacement, the flows cooled and crystallized a number of primary minerals, including pyroxene, plagioclase, magnetite, olivine, and apatite (DOE, 1982e, pp. 6.1-11 through 6.1-16). Glass of variable proportion and composition (Noonan et al., 1980, pp. 1 through 8) was also formed during rapid cooling of basalt flows. Cooling also led to the development of primary fractures.

The basalts of the reference repository location have undergone low-temperature (less than 100^{o}C (212^{o}F)) alteration, particularly in the fractures and flow tops that presented preferential groundwater pathways. This alteration appears to have caused the dissolution of the primary phases, especially the glass (Allen and Strope, 1983, pp. 1 through 10), with the subsequent precipitation of secondary minerals from ground water (Benson and Teague, 1982). These secondary minerals have been characterized and include smectite clay (principally nontronite), zeolite (principally clinoptilolite), and silica (DOE, 1982e, pp. 6.1-16 through 6.1-24; Benson and Teague, 1982). The formation of secondary minerals has led to the filling of most fractures and many of the vesicles of the flow tops (Long and WCC, 1984, pp. I-122 through I-133). The coupled dissolution and precipitation of minerals during alteration of basalt may, therefore, lead to a general decrease in the interconnection of fractures and flow tops that dominate the groundwater pathways in basalts (Long and WCC, 1984, pp. I-122 through I-133).

To confirm the expectation that similar dissolution and precipitation reactions will continue to occur after emplacement of nuclear waste, field tests and laboratory hydrothermal tests have been conducted. The preferential dissolution of interstitial glass leads to the precipitation of secondary minerals similar to those observed in fractures and vesicles (Apted and Myers, 1982, pp. 15 through 34; Grandstaff et al., 1984; Lane et al., 1983b, pp. 1 through 10; Long and WCC, 1984, pp. I-218 through I-221). Previous laboratory tests on basalt (Vandegrift et al., 1984, pp. 227 through 248), and granite and tuff (Moore et al., 1983) also indicate that hydrothermal alteration of silicate rocks (e.g., basalt) can lead to rapid clogging of pores and fractures by formation of secondary minerals, thus filling fractures through which radionuclides could migrate.

6.3.1.6.6 Conclusion on qualifying condition

The evidence supports a finding that the reference repository location meets the qualifying condition and is likely to continue to meet the qualifying condition (Level 4). Dissolution features are not considered present in basalt because its chemical and physical properties preclude significant dissolution. Chemical reactions of the basalt in the presence of heat and water lead to the dissolution of some minerals (primary minerals) found in the flow tops and fractures and subsequent precipitation of secondary minerals. However, these features occur in only a very small percentage of the rock.

6.3.1.7 Tectonics (Section 960.4-2-7)

6.3.1.7.1 Qualifying condition

"The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive tectonic processses or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period."

6.3.1.7.2 Evaluation process

Data used to assess the tectonic conditions and processes of the reference repository location for the past 15 million years include the following:

- Stratigraphic and structural information provided on geologic maps and cross sections that represent interpretations of direct observation and measurement of rock exposed at ground surface, direct observation of rock in core, extrapolation of observations between exposures and between boreholes, interpretation of exploration geophysical surveys (airborne and ground magnetic, gravity, seismic reflection and refraction, and magnetotelluric surveys), and limited exploratory trenching (Myers, Price et al., 1979; Myers, 1981; WPPSS, 1981).

- Instrumental and historical (pre-instrumental) records of seismicity obtained from published catalogs and from interpretation of recordings of earthquakes made on seismometers of various types, but mostly short-period, single-component vertical seismometers.

- Interpretations of geophysical anomalies that represent changes or contrasts in electrical, density, or magnetic properties of unexposed rocks, generally in fairly narrow zones (Myers, Price et al., 1979).

- Interpretation (Rohay and Davis, 1983; Prescott and Savage, 1984) of eight geodetic surveys conducted by the U.S. Geological Survey across the Hanford Site. The trilateration array surveyed consists of 19 stations and 29 lines that have been periodically surveyed using a single-color, laser, geodolite.

Tectonic data have been summarized in a number of geologic reports (e.g., see Section 2.1.2), most recently by Caggiano and Duncan (1983).

Interpretations and techniques of interpretation of geologic mapping, exploration geophysical surveys, earthquake monitoring, and geodetic surveys are state-of-the-art techniques and (or) are given in specific geologic reports or procedures. Interpretations of the tectonic stability of the reference repository location are preliminary because:

- Interpretations of subbasalt stratigraphy and structure are uncertain.

- Detailed monitoring of seismicity in the Cohassett flow and surrounding units is beginning and the impact of seismicity (e.g., fault radius, stress drop) have not been completed.

- Reconnaissance-level geologic mapping is complete (Myers, Price et al., 1979), but detailed studies of specific structures and interpretation of geophysical anomalies in the area of the reference repository location are ongoing.

- Kinematic analyses of fold development and the relationship of folding to faulting for Yakima folds remain to be completed.

6.3.1.7.3 Favorable condition

"The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment."

This favorable condition is expected to be present for igneous activity. This favorable condition is also expected to be present for tectonic deformation, based on its long-term, average low rate of deformation of the central Columbia Plateau. However, there is uncertainty due to the effects of expected deformation associated with microearthquake activity in the reference repository location. Therefore, the evidence supports a finding that the reference repository location is likely to meet the favorable condition.

Columbia River Basalt Group volcanism ceased approximately 6 million years ago (McKee et al., 1977). The youngest unit of Columbia River Basalt Group in the reference repository location is the 10.5-million-year-old Elephant Mountain Member of the Saddle Mountains Basalt (Myers, 1981). There are no known hot springs in the area of the reference repository location, nor is the area one of high-heat flow as might be expected in an area of Quaternary Period volcanism (Caggiano and Duncan, 1983). Quaternary volcanism has occurred in the western Columbia Plateau where Columbia River Basalt Group onlaps the Cascade Range; however, volcanism of the Simcoe volcanic series appears more closely allied to volcanism of the Cascade Range because of its calc-alkaline composition than to the tholeiitic basalt of the Columbia River Basalt Group.

Deformation of the Columbia River Basalt Group in the central and western Columbia Plateau into the east- and northwest-trending, anticlinal folds of the Yakima Fold Belt was under way by late-Grande Ronde Basalt time (16.5 million years ago) (Caggiano and Duncan, 1983). Thrust and reverse faults parallel to the axes of these folds have been mapped on anticlinal ridges (Myers, Price et al., 1979; Swanson et al., 1979, 1981). Northwest-trending, steeply dipping faults have been interpreted to be strike-slip faults, although the amount of displacement along such faults appears to be low (less than 5 kilometers (3 miles)). Developing structural relief (uplift) in the Miocene indicates that deformation was under way at long-term, average rates of 40 to 80 meters (131 to 262 feet) per million years (Reidel et al., 1983). Projecting these rates of structural uplift on anticlinal ridges to the present accounts for the present structural relief on Rattlesnake Mountain and the Saddle Mountains, suggesting that deformation has been ongoing at long-term, average low rates for at least 15 million years. Focal mechanism solutions of earthquakes indicate that the north-south, nearly horizontal compression that formed these ridges is still ongoing (Rohay and Davis, 1983). Shortening of the lines of a trilateration survey similarly suggest that deformation is ongoing at low rates of strain that are compatible with rates for the Miocene (see Subsection 3.2.3.8).

A seismic exposure analysis has been completed for the U.S. Nuclear Regulatory Commission-licensed Washington Public Power Supply System operating plant WNP-2 located on the Hanford Site. This analysis conservatively estimated the probability of exceeding peak vibratory ground motions of the safe shutdown earthquake (0.25 g). The annual probability of exceedance is estimated to be 1.1×10^{-4} (WPPSS, 1981). This estimate of seismic exposure is indicative of the low tectonic activity of the central Hanford Site.

The rate and pattern of deformation determined for the Pasco Basin area of the central Columbia Plateau are preliminary and remain to be confirmed. Consequence analyses of disruptive event scenarios to determine the effects of this pattern and style of deformation on waste isolation over the next 10 000 years have yet to be performed. In the judgment of experts surveyed in a Delphi analysis to test this method for evaluating disruptive event scenarios, the pattern of deformation should continue in the reference repository location over the next several thousand years (Davis et al., 1983). Final analyses of disruptive event scenarios involving tectonic effects remain to be performed.

Within the first 10,000 years after closure, there is a reasonable likelihood of microearthquakes occurring within the basalt sequence in or adjacent to the reference repository location. However, the effects of microearthquakes are not expected to result in releases of radionuclides to the accessible environment. Microearthquakes are considered to be the tectonic event that has the highest likelihood of occurring in the vicinity of the reference repository location. These microearthquakes could affect the permeability along a portion of the ground-water flow path. Therefore, an analysis to support a contention that the favorable condition is likely to be present requires an understanding of the impacts of this tectonic event on the waste package and on the ground-water flow paths for radionuclide transport to the accessible environment. Detailed site characterization and scenario definition will be required to support an analysis suitable for use in a license application. However, qualitative judgments of potential impacts, based on existing data and interpretations, can offer a perspective on the likelihood of radionuclide releases to the accessible environment resulting from microseismic activity in or adjacent to the Cohassett flow in the reference repository location.

The tectonic history and discussion of the rates of tectonism provide a basis for postulating several ground rules for a simple analysis of the effects of microseismic activity and for assuming that the probability of some effects was sufficiently low that these effects could be ignored. The assumptions and hypotheses of particular importance are discussed below.

- Tectonic events are not likely to create major new vertical ground-water flow paths that traverse a substantial number of basalt flows above the repository horizon (i.e., one or several flow tops overlying the Cohassett flow will continue to be the most significant flow paths to the accessible environment). From the geologic record, it appears that deformation tends to continue along established geologic structures. Therefore, if waste packages are not emplaced in fault zones, the likelihood of rupturing a container is low.

- The magnitude of a potential earthquake occurring in or adjacent to the repository underground layout area in 10,000 years is expected to be low. Moderate- to large-magnitude seismic events (greater than or equal to magnitude 5) are considered unlikely, because (1) estimated robabilities of occurrence of larger seismic events in or adjacent to the reference repository location would be less than 1 chance in 10,000 within the next 10,000 years and (2) seismogenic structures to support larger events with short recurrence intervals have not been identified in the reference repository location (see Section 3.2.3). Uncertainty in this assessment would be resolved during site characterization.

- Shears or faults that might produce seismic events in the reference repository location are likely to be sufficiently inclined (see Section 2.1.3) and of limited rupture radius so that they should preclude shearing of more than one thick basalt flow interior. In addition, no more than one such fault event would be expected in or adjacent to the underground repository layout area within 10,000 years after closure.

- The area of the rupture plane that could produce a low-magnitude seismic event is expected to be small, thus resulting in minimal slip along existing joints and shears. The creation of a new shear zone is considered unlikely. Such an areally limited physical disturbance is not likely to increase the permeability of the flow interior to values greater than the permeability of typical Grande Ronde Basalt flow tops. The compressive stresses and lithostatic load at repository depth in the reference repository location are expected to maintain a network of cooling joints and shear zones of small aperture, thus minimizing any potential permeability increase through a basalt flow interior. Some uncertainties exist about the hydrologic characteristics of shear zones and cooling joints at repository depth in the reference repository location. These uncertainties need to be resolved.

- The offset of the rupture surface associated with a low-magnitude seismic event is likely to be small (a few centimeters (inches)).

From the previously stated assumptions and hypotheses, a qualitative analysis of the overall repository system (waste package and site subsystems) can be formulated.

- The most likely fault rupture (assuming any occurs) is expected to be of minimal surface area and, thus, it is not likely to result in a premature loss of containment from a waste container, since the (1) waste packages will not be emplaced in fault zones, (2) small offset (few centimeters (inches)) along a rupture surface is possible, (3) thickness of the waste container (8.3 centimeters (3.3 inches)) should be adequate to prevent waste container rupture resulting from expected fault offset, and (4) packing material thickness (19.8 centimeters (7.6 inches) between the container and the basalt) and composition (mixture of bentonite and crushed basalt) are likely to accommodate any expected offset associated with a shear surface so as not to rupture a waste container. Therefore, the waste container mean lifetime (estimated in Subsection 6.4.2.4.2) is not expected to change from 6,100 years plus or minus 600 years due to tectonic activity.

- The permeability along the rupture surface or affected network of cooling joints and shears is not expected to be greater than any of the flow-top permeabilities considered in estimates of the pre-waste-emplacement ground-water travel times (Subsection 6.4.2.6.1). Since these travel-time estimates do not include vertical travel through the dense interior in which the repository is constructed, the pre-waste-emplacement ground-water travel times are considered reasonable estimates of postclosure ground-water travel time. Changes induced by tectonic events will not have a significant effect on the travel-time distributions reported in Subsection 6.4.2.6.1, particularly for the low end of the travel-time range that reflects paths through the first flow top. The principal results of the travel-time analyses in Subsection 6.4.2.6.1 indicate there is a probability of between 0.78 and 0.81 for the pre-waste-emplacement ground-water travel time to the accessible environment exceeding 10,000 years.

Based on the above assumptions and qualitative analysis, microseismic activity is expected to occur in or near the reference repository location during the postclosure period. However, the effects from microseismic activity are not likely to affect releases of radionuclides to the accessible environment during the first 10,000 years after closure. This position is supported by the small fracture dimensions associated with a microseismic event coupled with a favorable geochemical environment, long (i.e., likely to be greater than 10,000 years) ground-water travel-time estimates, and a long (6,100 years plus or minus 600 years) expected mean lifetime of waste containers.

6.3.1.7.4 Potentially adverse condition

"(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period."

This potentially adverse condition is present within the geologic setting of the reference repository location, since faults that have been interpreted to be active during the Quaternary Period are present within the Columbia Plateau.

Deformation at long-term, average low rates can explain the present structural relief of the Saddle Mountains and Wanapum Basalts on Rattlesnake Mountain and the Saddle Mountains (Reidel et al., 1983). Geodetic surveying as well as the level, pattern, and distribution of small earthquakes indicate that deformation is continuing and appears to follow trends that were established by at least Miocene time (Rohay and Davis, 1983). The timing and role of faulting in the deformational process are not clearly understood. Faulting appears to be concentrated in the steep limbs of anticlinal folds, with little faulting or folding occurring in synclinal troughs such as the Cold Creek syncline. (Small-scale strain features, including thin tectonic breccia zones, shear zones, and disking, have been identified in the Cold Creek syncline and the reference repository location.) It is not certain to what depths mapped faults extend, when in the structural evolution they developed, or the mechanical relationship between folding and faulting. The age of development and slip and recurrence rates of many faults remain to be determined.

A thrust fault, located on Gable Mountain approximately 9 kilometers (5 miles) northeast of the reference repository location and separating two second-order anticlines with opposite vergence, has been interpreted as a tear fault (PSPL, 1982, Section 20; NRC, 1982). Trenching through the Central fault on Gable Mountain (see Fig. 3-19) has revealed displacements in stratified sands of presumably very late-Wisconsinan age that continue along the trends of displacement in the basalt and interbeds (PSPL, 1982, Section 20). The displacements were observed along approximately 335 meters (1,100 feet) of the fault, with a maximum observed dip-slip displacement of approximately 6 centimeters (0.2 foot) (PSPL, 1982). These data suggest that the Central fault on Gable Mountain may still be active; however, the offsets may be due to other than tectonic processes, such as rapid loading and unloading during catastrophic flooding (see Subsection 3.2.3.2). Data from the instrumental period of earthquake monitoring at the Hanford Site suggest that the Central fault is not seismically active. Other faults (such as associated with the Rattlesnake-Wallula alignment (see Fig. 3-19)) have been assumed active in the absence of definitive evidence to the contrary and because this structure continues along the northwest trend of steeply dipping faults that appear active in the area of Wallula Gap (WPPSS, 1981; NRC, 1982). These faults do not appear to be active seismogenic structures based on the apparent lack of association of these structures with instrumentally located earthquakes over the past 14 years (Caggiano and Duncan, 1983).

Deformation at long-term, average low rates of strain and apparent stability of synclinal areas would appear to provide a favorable environment for isolation of radioactive waste in a repository. Although detailed modeling has been planned, it has yet to be performed on tectonic effects and their potential for changes in the geohydrologic system (Section 6.4.2).

Diapirism is a deformational phenomenon involving materials of very low shear strength and typically involves evaporites (e.g., gypsum, anhydrite, or salt). There are no known gypsum, anhydrite, or salt strata interbedded within or underlying the Columbia River Basalt Group; therefore, diapirism is not a concern at the reference repository location.

Relative to the stable Palouse slope that has been used as a datum, uplift on Rattlesnake Mountain and the Saddle Mountains and subsidence of the Cold Creek syncline appear to be continuing at long-term, average low rates of approximately 40 meters (130 feet) per million years (Reidel and Fecht, 1981; Reidel et al., 1983). These rates, when projected 10,000 or more years into the future, would lead to increased elevation of Rattlesnake Mountain and the Saddle Mountains and to further subsidence of basalt strata in the Cold Creek syncline, neither of which would lead to increased potential for erosion in the Cold Creek syncline. Therefore, uplift and subsidence continuing along the extant pattern and rates would appear not to jeopardize isolation of radioactive waste at the reference repository location.

Columbia River Basalt Group volcanism ceased approximately 6 million years ago (McKee et al., 1977). The youngest unit of the Columbia River Basalt Group in the reference repository location is the 10.5-million-year old Elephant Mountain Member of the Saddle Mountains Basalt (Myers, 1981). No known hot springs are in the area of the reference repository location, nor is the area one of high heat flow as might be expected in an area of Quaternary volcanism (Caggiano and Duncan, 1983). Quaternary Period volcanism has occurred in the western Columbia Plateau where the Columbia River Basalt Group onlaps the Cascade Range. However, volcanism of the Simcoe volcanic series appears more closely allied to Cascade volcanism because of its calc-alkaline composition compared with tholeiitic basalt of the Columbia River Basalt Group. The Columbia Plateau is considered to have been volcanically inactive during the Quaternary Period.

6.3.1.7.5 Potentially adverse condition

"(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation."

Recurrence of a large historical earthquake within the geologic setting is not expected to affect waste containment or isolation in the reference repository location, although considerable uncertainty exists that would be addressed during site characterization (see Subsection 4.1.1.2). Therefore, the evidence does not support a finding that this potentially adverse condition is present at the reference repository location.

Deformation of the Columbia River Basalt Group in the central Columbia Plateau has apparently been proceeding at long-term, average low rates under a regime of nearly north-south, nearly horizontal compression for at least 15 million years (Caggiano and Duncan, 1983). The pattern of folding accompanied by faulting appears to have been established during Miocene time. Data do not permit the precise determination of slip-recurrence rates on specific faults; however, the pattern and timing of deformation suggest that slip rates of faults during the late-Cenozoic have been low. This pattern suggests that earthquakes would be relatively small and recurrence rates generally long compared with active plate boundaries (e.g., as in California). This pattern is supported by the following evidence.

- The 1936 Milton-Freewater, Oregon, event is the largest earthquake recorded on the Columbia Plateau (magnitude 5.75) and located on the Blue Mountains front.

- The average recurrence interval for a large earthquake (magnitude 6.5) on a 20-kilometer (12-mile) segment of the Rattlesnake-Wallula alignment is estimated to be greater than 50,000 years (Slemmons, 1982).

- The largest earthquake recorded during 15 years of instrumental monitoring of earthquakes in the vicinity of the Hanford Site had a magnitude of 4.4, and was located more than 40 kilometers (24 miles) northeast of the boundary of the reference repository location and outside of the Pasco Basin. The largest earthquake recorded in the Pasco Basin is a magnitude 3.8 located approximately 10 kilometers (6.2 miles) north of the boundary of the reference repository location. Earthquakes in the Pasco Basin are generally shallow (most are less than 4 kilometers (2.5 miles) deep) and generally small (less than magnitude 2.5). Shallow swarms have not been recorded in the reference repository location (see Subsection 2.1.1.3 and Section 3.2.4).

6.3.1.7.6 Potentially adverse condition

"(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase."

The tectonic investigations and historical earthquake records suggest that the frequency or magnitude of earthquakes within the Columbia Plateau will not increase. However, there are faults on the Columbia Plateau that are interpreted to have been active during the Quaternary Period. Some of these faults potentially could be associated with magnitudes larger than the historic maximum magnitude. Therefore, it appears that this potentially adverse condition may be present within the geologic setting of the reference repository location.

The areas reported to be most seismically active are along and beyond the margins of the Columbia Plateau in Puget Sound (Myers, Price et al., 1979), the Cascade Range, and along the front of the Blue Mountains. Larger earthquakes that have occurred in the Puget Sound lowlands are interpreted to have depths greater than 30 kilometers (19 miles) and to be related to subduction of the Juan de Fuca Plate beneath the North American Plate. Larger events in the western portion of the plateau appear similar to recent events in the Cascade Range, which seem to be occurring on nearly north-south- to northwest-striking strike-slip faults. Events in the central portion of the plateau seem to be restricted to a 28-kilometer- (17-mile-) thin crust, with most occurring in the upper 10 kilometers (6.2 miles). These events are small (generally less than magnitude 3.0, but ranging up to magnitude 4.4), largely reverse slip events occurring on steeply dipping planes of generally east-west orientation under nearly north-south compression. Events along the front of the Blue Mountains occur near the intersection of two prominent geologic structural trends (i.e., the northwest trend of the Rattlesnake-Wallula alignment and the northeast trend of the Hite fault system (see Fig. 3-19)). The largest known event in the Columbia Plateau occurred on July 16, 1936, along the front of the Blue Mountains near the intersection of these two structural trends (WPPSS, 1981, pp. 2.5-118 and 2.5-119). This event is reported to be a magnitude 5.75. Focal mechanisms for the 1936 event (although poorly constrained) indicate probable strike slip along a northeast-trending fault. Focal mechanism solutions for two instrumentally recorded, more recent events close to the source of the 1936 event (a magnitude 4.1 in April 1979 and a magnitude 3.8 in March 1983) also suggest that the motion was dominantly strike slip along either northeast- or northwest-trending planes. The axes of maximum compression determined for these events were nearly east-west; different from the nearly north-south compression characteristic of the central portion of the plateau.

Earthquakes are not associated with mapped geologic structures, nor do hypocenters align in a manner suggestive of unmapped, buried, steeply dipping faults in the Pasco Basin area. Composite focal mechanism solutions for events of presumably similar origin suggest that slip occurs on different planes and not along one planar zone. Therefore, it is assumed that several planes are slipping during events within one swarm of earthquakes. Because it is generally assumed that earthquakes result from the propagation of energy released when rock fractures and (or) slips occur during rupture, some faults must exist that are seismogenic. Judging from the size of earthquakes and the distribution of events, the size of such faults must be small (tens of square meters (feet) to a few square kilometers (miles)), although some of these faults potentially could be associated with magnitudes larger than the historic maximum magnitude.

The pattern and rate of deformation in the Columbia Plateau that appear to have been in effect since the Miocene are not expected to change over the lifetime of a repository. Therefore, there is no indication that the pattern, frequency, or distribution of earthquakes on the Columbia Plateau will change over the next 10,000 years. The frequency or magnitude of earthquakes could potentially increase given the presence of potentially active faults, evidence suggesting contemporary deformation, relatively short time interval of historic earthquake record, and low to moderate seismicity. It is expected, however, that possible increases in frequency or magnitudes of earthquakes within the geologic setting would be unlikely to affect waste isolation adversely within the reference repository location. An increase in seismicity would be expected to occur on existing major geologic structures that are located outside of the reference repository location. Plans for seismic surveillance (see Section 4.1.2) should provide data to develop detailed recurrence curves for the reference repository location area, which can be compared with data from the 17-year operating regional array, the more than 100 years of historical earthquake data, and the geologic record.

6.3.1.7.7 Potentially adverse condition

"(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located."

Seismic activity within the Columbia Plateau occurs less frequently and at lower magnitudes than in other areas of the Pacific Northwest (Myers, Price et al., 1979). Therefore, it appears that this potentially adverse condition is not present within the geologic setting of the reference repository location.

Historical seismicity as well as instrumentally recorded events show the Columbia Plateau to be an area of low to moderate seismicity (see Subsection 2.1.1.3 and Section 3.2.4) (Rasmussen, 1967; WPPSS, 1981; Myers, Price et al., 1979). Earthquakes in the Columbia Plateau are confined to a thin crust (less than 28 kilometers (17 miles) in depth), are less than magnitude 5.8 (the largest historically recorded event is magnitude 5.75), and are commonly less than magnitude 4. In the central Columbia Plateau the seismicity is characterized by swarms of shallow (less than 4 kilometers (2.5 miles)), small-magnitude earthquakes (less than magnitude 3.5, most less than magnitude 2.5). These events are temporally and spatially restricted to small volumes of rock. There is no distinct mainshock and no distinct buildup or decay of events in terms of size or frequency leading to or away from a main event. Focal mechanism solutions suggest that different planes are rupturing during swarm events. Earthquakes are not clearly related to mapped faults nor do focal mechanisms align in a manner suggestive of unmapped, steeply dipping faults. Swarms have occurred along the flanks of major anticlinal uplifts (e.g., Saddle Mountains), but also occur elsewhere where geologic structures have not been mapped (e.g., Wooded Island; see Fig. 2-11).

Most earthquake activity in the State of Washington occurs in the Puget Sound lowlands, which continues to the south in the Willamette Valley of Oregon. The zone of relatively high activity continues to the northwest into British Columbia in the area of southern Vancouver Island, the Straits of Georgia, and the Straits of Juan de Fuca. Near the center of Vancouver Island, the zone of high activity appears to turn westward and join the zone of high earthquake activity along active, spreading centers and transform faults.

Earthquakes as large as magnitude 7.0 and at depths greater than 30 kilometers (19 miles) have occurred in the Puget Sound area. Historic seismicity, as well as instrumentally recorded events, shows that this is an area where moderate to high levels of stress have been relieved over the nearly 150 years of record. Most earthquakes and most larger events occur at depths of greater than 10 kilometers (6.2 miles) in distinct contrast to the Columbia Plateau.

East of the Columbia Plateau, earthquake activity is low, except for a zone extending northwestward from the generally north-trending Intermountain Seismic Belt, which runs across southern Idaho north of the Snake River Plain. This zone, known as the Idaho Seismic Belt, is an area of shallow earthquakes identified from felt reports and more recently from instrumental records, and extends through the Idaho Batholith Province. The magnitude 7.3 Borah Peak (Idaho) earthquake occurred in this zone. Earthquakes in this area are generally less than 15 kilometers (9 miles) deep, of moderate to high magnitude (magnitude less than 7.5), and correlate in part with post-Miocene faults. The Snake River Plain is an area of low earthquake activity from historical felt reports and instrumental surveys.

One of the largest earthquakes felt over a large area of the Pacific Northwest occurred on December 14, 1872, in a remote, mountainous area of sparse population. This earthquake was not recorded by instruments, so its size and location were determined from written records. A panel of experts was formed to review felt reports of the December 14, 1872, event (WPPSS, 1977b). The panel concluded that the 1872 earthquake occurred in the area enclosed by the Modified Mercalli Intensity VIII isoseismal line extending from Lake Chelan on the south to southern British Columbia on the north. It apparently had a depth greater than 10 kilometers (6 miles), was followed by several aftershocks, and was probably a low-stress-drop earthquake. The resultant isoseismal map indicates that the earthquake was felt over an area of approximately 1.3 million square kilometers (500,000 square miles), but the large felt area may have been the cumulative effect of the main shock plus several aftershocks.

Subsequent reviews and hearings in the late 1970's by the U.S. Nuclear Regulatory Commission with regard to licensing Washington Public Power Supply System operating plant WNP-2 on the Hanford Site resulted in some agreement on the December 14, 1872, earthquake. It was agreed that the epicenter is in a broad region in the North Cascades-Okanogan Highlands, which is a tectonic province separate from the Columbia Plateau.

6.3.1.7.8 Potentially adverse condition

"(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system."

It does not appear that natural phenomena would create large-scale surface-water impoundments resulting in significant changes to the regional ground-water flow system. Therefore, this potentially adverse condition is not expected to be present within the geologic setting of the reference repository location.

Slope instability on the White Bluffs along the Columbia River (located approximately 16 kilometers (10 miles) northeast of the reference repository location) is evident where topographic features indicate relatively recent landslides (late-Holocene to present). Scarps and slide debris are evident along parts of the White Bluffs (see Fig. 3-37), especially where the ground-water level in the sediments overlying the basalt has been raised in recent years by irrigation of croplands (Hays and Schuster, 1984). Morphologic evidence also indicates areas of slope instability along the incised channel of the Columbia River downriver from Wallula Gap, where the Columbia River has incised the Horse Heaven Hills (see Fig. 3-1). The volumes of material in these slides appear insufficient to affect the course or to dam the Columbia River. Even if the river were to be dammed by a slide of magnitude much larger than those in evidence today, it would probably be an ephemeral event not lasting more than a few months or years. The net effect of such an event on the water-table elevation beneath the reference repository location would probably be no greater than a few meters (feet). The effects of this change on the deep, regional flow system beneath the reference repository location would likely be insignificant.

Damming of the Columbia River by volcanism is unlikely in the Pasco Basin area. However, there is geologic evidence that the ancestral Columbia River Gorge was blocked in Miocene time by flows of the Columbia River Basalt Group, producing temporary lakes. Eruptions of high-alumina basalts also blocked the ancestral Columbia River Gorge approximately 2 million years ago in the area where it flowed through the Cascade Range (Tolan, 1982, pp. 112 through 117 and 129 through 131). This blockage occurred along the Columbia River in the Cascade Range approximately 320 kilometers (200 miles) downstream from the closest point of the reference repository location. The volume and rapidity of movement of these flows were sufficient to fill the existing channel, causing the ancestral Columbia River to relocate to its present channel. Assuming lava flows were to inundate the Columbia River channel in the area of the present-day Columbia River Gorge through the Cascade Range, the blockage would result in an obstruction. In a worst-case scenario, a blockage could temporarily impound surface waters in topographic depressions along the course of the Columbia River and its tributaries. Surface-water could conceivably be impounded as far upstream as the Pasco Basin. This impoundment would be expected to change temporarily the local, shallow ground-water flow systems with less long-term impact on deeper, regional flow systems. The probability of volcanic flow impounding the Columbia River is considered to be low and will be assessed if the reference repository location were recommended for characterization.

6.3.1.7.9 Potentially adverse condition

"(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system."

The low rate of deformation is not expected to affect adversely the regional ground-water flow system. Therefore, the evidence does not support a finding that this potentially adverse condition is present in the reference repository location.

Assuming tectonic deformation will continue at long-term, average low rates as it apparently has since at least the Miocene (15 million years ago), the incremental change in tectonic deformations during the postclosure period (10,000 years) is expected to be small. These deformations would be a continuation of geologic processes that have formed the structural features of the Columbia Plateau and that have been acting on the regional ground-water flow system. Over the postclosure period of 10,000 years, tectonic deformations are not expected to affect adversely the regional ground-water flow system.

6.3.1.7.10 Disqualifying condition

"A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur."

The nature and rates of fault movement or other ground motion at the reference repository location are not expected to result in a loss of waste isolation. The evidence does not support a finding that the reference repository location is disqualified (Level 1).

The pattern and timing of deformation of the central Columbia Plateau suggest that slip rates of faults during the late-Cenozoic have been low. Such a pattern would suggest that earthquakes and rupture planes would be relatively small and recurrence rates generally long (see Subsection 6.3.1.7.5). Recurrence rates for moderate earthquakes are long (greater than 50,000 years for large earthquakes (Slemmons, 1982)) (see Subsection 6.3.1.7.5); these rates indicate the relatively infrequent nature of moderate earthquakes in the central Columbia Plateau (see Subsection 2.1.1.3 and Section 3.2.4).

Detrimental effects to mines are noted if rupturing faults intersect mine walls. Therefore, major consideration was given to siting the reference repository location away from known or suspected faults (see Section 2.2). Structural analysis of the Yakima Fold Belt in the central Columbia Plateau shows that little faulting and folding have occurred in synclinal troughs. The reference repository location has been sited near the trough of the Cold Creek syncline. Seismic data suggest that the probability of detrimental ground motion at a repository in the reference repository location is low and related to small earthquakes. Rupture planes from small earthquakes are not expected to lead to a loss of waste isolation (see Subsection 6.3.1.7.3).

6.3.1.7.11 Conclusion on qualifying condition

A final conclusion on the postclosure qualifying condition for tectonics cannot be made based on available data. However, the evidence does not support a finding that the reference repository location is not likely to meet the postclosure qualifying condition for tectonics (Level 3).

This preliminary interpretation is based on (1) the rate, pattern, and timing of deformation of the Columbia River Basalt Group, (2) the low to moderate seismicity, (3) the areal distribution and size of earthquakes, (4) the low heat flow and unlikely renewal of basaltic or other volcanism in the central Columbia Plateau, and (5) the unlikely occurrence of significant changes in ground-water pathways or travel time in the reference repository location as a result of tectonic processes or events. Studies used to arrive at this interpretation are summarized in Caggiano and Duncan (1983) and include stratigraphic and structural investigations, seismic monitoring and seismological investigations, geophysical investigations and interpretations of anomalies, and geodetic monitoring. The preferred interpretation is that deformation is following a pattern established at least 15 million years ago in the Miocene, in which structures have been developing under nearly north-south, nearly horizontal compression at long-term, average low rates of strain. The pattern of developing structural relief during eruption of the Columbia River Basalt Group from at least 14.5 to 10.5 million years ago apparently continues to the present.

Growth rate projections of major anticlinal folds in the Saddle Mountains and on Rattlesnake Mountain from the Miocene accounts for the present elevation of these two Yakima fold ridges. The size, pattern, and distribution of earthquakes in the central Columbia Plateau along with focal mechanism solutions suggest continuing strain under nearly north-south, nearly horizontal compression. Eight surveys of a trilateration array across the Hanford Site since 1972 suggest compression at very low rates. These rates are compatible with geologically determined rates of deformation, although the data may be within the limits of error for the instruments used to measure changing line lengths.

The qualitative assessment in Subsection 6.3.1.7.3 provides indications that a microseismic event in the deep basalts at the reference repository location is not unlikely to compromise the waste-isolation requirements for a repository. The analyses were based on field and laboratory measurements, reasonable assumptions, expert judgment, and conceptual models that reflect an understanding of the geohydrologic and geochemical characteristics of basalt deep beneath the Hanford Site. Microearthquakes are considered to be the type of tectonic event that has the highest likelihood of occurring in the vicinity of the reference repository location thus potentially affecting ground-water flow paths. Since a microseismic event is not expected to result in radionuclide releases greater than allowed, it is expected that tectonic deformations in the central Columbia Plateau will not lead to radionuclide releases greater than those allowed.

The preferred interpretation of deformation in the Columbia Plateau is one of continuing deformation under nearly north-south, nearly horizontal compression at long-term, average low rates. There is the possibility of shorter periods in which deformation proceeded at higher rates (i.e., a more episodic pattern and rate of deformation compared with a long-term, average low rate). The rate and timing of deformation in other Yakima folds need to be confirmed, as does the low rate of strain determined geodetically. Instrumental monitoring of shallow microearthquakes in the reference repository location needs to be conducted to determine the recurrence of microearthquakes in the reference repository location, source parameters for these events, and effects of such rupture on ground-water pathways and travel times. The relationship of folding to faulting and the relationship of deformation in basalt to subbasalt structure need to be determined.

6.3.1.8 Human interference (natural resources) (Section 960.4-2-8)

"The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in Sections 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness."

6.3.1.8.1 Qualifying condition

"This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1."

6.3.1.8.2 Evaluation process

Data to assess the natural resources in the region of the reference repository location include the following:

- Past oil and gas production and present oil and gas exploration.
- Past coal production.
- Past gold production.
- Past industrial rock and mineral production.
- Economic analysis of the area within 100 kilometers (62 miles) of the Hanford Site.

- Projected net value of mineral resources during the next 25 years.
- Past ground-water production.
- Geothermal analysis.

6.3.1.8.3 Favorable condition

"(1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource."

There are no known metalliferous or petroliferous natural resources that have, or are projected to have in the foreseeable future, a value great enough to be considered commercially extractable at the reference repository location. However, shallow, potable, ground-water resources are present. Therefore, this favorable condition is not present at the reference repository location.

The 200,000-square-kilometer (78,000-square-mile) area underlain by the Columbia River Basalt Group, including the area within 100 kilometers (62 miles) of the reference repository location, is not part of a metalliferous or petroliferous geologic province. Natural resource evaluations of the Pasco Basin are presented in reports by Geosciences Group/George Leaming Associates (GG/GLA, 1981) and Campbell (1985). The Geosciences Group/George Leaming Associates report (GG/GLA, 1981) is mainly directed at the Hanford Site, which includes the reference repository location. The Campbell (1985) report evaluates hydrocarbon exploration in the Columbia Basin (the Columbia Plateau of the State of Washington).

No commercial production of coal has been recorded within 100 kilometers (62 miles) of the Hanford Site. Within the Pasco Basin, relatively thin, low-grade coaly zones (lignite) in sediments interbedded with basalt flows of the Columbia River Basalt Group have been shown to be too thin, impure, and of low rank to be attractive for potential exploration and development in the foreseeable future. This was based on analysis of geophysical logs and vitrinite reflectance.

A small, depleted, low-pressure, natural gas field that was in production from 1929 to 1941 is present at the southern edge of the Hanford Site, 11 kilometers (7 miles) south of the reference repository location. No other current or past commercial production of petroleum or natural gas has been reported within 100 kilometers (62 miles) of the Hanford Site. Interpretation of carbon and hydrogen isotopic data for methane gas from confined aquifers of the Wanapum and Saddle Mountains Basalts in the vicinity of the Hanford Site and within the reference repository location suggest that the gas probably originated at shallow depths. The gas probably originated from terrestrial carbonaceous matter in the interbeds of the Ellensburg Formation or sedimentary rocks beneath its basalt sequence rather than from marine sediments at depth. Based on the relatively small content of carbonaceous matter and the limited volume of sedimentary interbeds, it is concluded that the potential for intra-basalt natural gas development in the reference repository location is relatively unattractive.

The potential for oil and gas in sedimentary strata underlying the Columbia Plateau at depths in excess of 3,000 meters (10,000 feet) is at best speculative. Four wells have been drilled by Shell Oil Company and by Atlantic Richfield Company in this frontier area. All wells have been deemed noncommercial by the oil companies, although natural gas was recovered from the wells. Of the four wells, that closest to the Hanford Site is located in the Saddle Mountains, 26 kilometers (16 miles) north of the reference repository location. This well drilled through the Columbia River Basalt Group at a depth of nearly 3,658 meters (12,000 feet) and is the deepest well in the State of Washington (over 5,180 meters (17,000 feet)).

Recent hydrocarbon exploration activities have been directed toward the sedimentary sequence beneath the basalt. The well sites of Shell Oil Company have been situated within the closure of surface anticlines of the Yakima Fold Belt and are aligned with Tertiary basins that project southeastward under the fold belt. The Columbia River Basalt Group is the cap rock for some of the natural gas that has been found, but rock seals must exist below the Columbia River Basalt Group as well, since zones of natural gas are detected within the subbasalt sedimentary rock sequence.

With the exception of small gold placers, no high-unit-value metallic mineral resources with significant commercial potential are known or believed likely to exist within the Columbia River Basalt Group or in overlying or interbedded sediments within 100 kilometers (62 miles) of the Hanford Site. Mineral potential in subbasalt sedimentary rocks is not known, but the great depth from surface to these rocks within the Pasco Basin (3,000 meters (10,000 feet) or more) precludes foreseeable exploration and development of possible minerals within subbasalt sediments.

Relatively low-unit-value industrial rocks and minerals within 100 kilometers (62 miles) of the Hanford Site consist of peat, diatomaceous earth, pumicite, quarry rock, and sand and gravel. Such resources are surficial, and are not concentrated within the Pasco Basin relative to the remainder of the Columbia Plateau. Current mineral-industry activities within 100 kilometers (62 miles) of the Hanford Site are limited to production of diatomaceous earth, sand and gravel, and crushed stone (all from surface mining operations).

The average geothermal gradient obtained from 15 boreholes drilled in the Pasco Basin, ranging in depth from approximately 300 to 1,500 meters (approximately 1,000 to 5,000 feet), is approximately 38°C per kilometer (162°F per mile). These data agree with the temperature gradient contour map of the State of Washington shown by Stoffel and Korosec (1984). Stoffel and Korosec (1984) state that, although much of the Columbia Basin (i.e., central Columbia Plateau) has potential for space heating energy, the Hanford Site is located in the nonfavorable area that is defined in the report as an area where geothermal gradients are less than 45°C per kilometer (182°F per mile). Temperatures greater than 45°C per kilometer (182°F per mile) were considered favorable for space heating energy by Stoffel and Korosec (1984).

Economic analysis (GG/GLA, 1981) of the area within 100 kilometers (62 miles) of the Hanford Site indicates that the gross value of known resources of diatomaceous earth, sand and gravel, stone, peat, and placer gold and the probable gross value of remaining undiscovered natural gas resources within the Columbia River Basalt Group is about 470.5 million dollars (in 1980 dollars). Subtracting estimated costs of exploration, development, production, and wholesale marketing from the gross resource value leaves a net value of 33.0 million dollars (in 1980 dollars). Present net value (in 1980 dollars) of known resources and resources likely to be recovered over the next 25 years is between 7.3 and 10.4 million dollars, depending on the discount rate used to compute present value.

Projected net value of mineral resources over the next 25 years for the 10-county area within 100 kilometers (62 miles) of the Hanford Site is 62 dollars per capita (in 1980 dollars). For the 11-county remainder of the Columbia Plateau, projected net mineral resource value averages 98 dollars per capita.

In 1978, personal income derived from extraction of geologic resources in the 10 counties within 100 kilometers (62 miles) of the Hanford Site was 4.5 million dollars or 77 dollars per square kilometer (200 dollars per square mile), amounting to 8 dollars-40 cents per capita. In the remaining 11 counties of the Columbia Plateau, comparable figures were 126 dollars per square kilometer (326 dollars per square mile), amounting to 10 dollars-33 cents per capita. The mining industry of the 10-county area closest to the Hanford Site provided 0.5 job per 1,000 residents in 1978. Comparable figures for the remainder of the Columbia Plateau were 0.7 job per 1,000 residents. By comparison, exploitation and exploration for geologic resources in New Mexico in 1978 provided 23 jobs per 1,000 residents. Projected government revenue derived from mining in the 10-county area nearest the Hanford Site over the next 25 years is 36 cents per 1980 resident. Comparable figures are 16 cents per capita for the 11-county remainder of the Columbia Plateau.

It is concluded that the mineral industry within 100 kilometers (62 miles) of the Hanford Site, including the reference repository location, is an insignificant component of employment, personal income, and governmental revenue derived from all mineral resources. Geologic assessment of the reference repository location and vicinity suggests that they are unattractive for future subsurface mineral exploration and development relative to other areas of the Columbia Plateau and the western United States.

As addressed in Subsection 6.3.1.1.9, deep ground waters within the reference repository location contain fluoride at concentrations greater than safe drinking water limits established by the U.S. Environmental Protection Agency (EPA, 1976). Similarly, sodium and salinity concentrations in Grande Ronde Basalt ground waters are of concern relative to their use for crop irrigation without treatment. However, shallow aquifers occurring in sediments overlying the basalts and within interbeds and flow tops of the Saddle Mountains Basalt contain ground water suitable, without treatment, for human consumption and crop irrigation (see Subsections 6.3.1.1.9 and 6.3.3.3.3). It is for this reason that this favorable condition is not present at the reference repository location.

6.3.1.8.4 Favorable condition

"(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment."

The deep ground waters beneath the reference repository location do not contain total dissolved solids equal to or greater than 10,000 parts per million. Therefore, this favorable condition is not present at the reference repository location.

The values for total dissolved solids for ground waters along likely radionuclide travel paths to the accessible environment are less than approximately 1,200 parts per million (see Section 3.3.2) (Gephart et al., 1979, p. III-187).

6.3.1.8.5 Potentially adverse condition

"(1) Indications that the site contains naturally occurring materials, whether or not actually identified, in such form that (i) economic extraction is potentially feasible during the forseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting."

There are indications that the reference repository location contains naturally occurring materials (i.e., ground-water resources and natural gas) in such form that economic extraction is potentially feasible during the foreseeable future. Ground-water resources (i.e., ground water suitable for human consumption and crop irrigation without treatment) are present in the Saddle Mountains Basalt ground-water flow system. The potential for economic extraction of hydrocarbons from beneath the Columbia River Basalt Group at the reference repository location is speculative. Therefore, this potentially adverse condition appears to be present at the reference repository location.

Shallow aquifers occurring in sediments overlying the basalts and within interbeds and flows of the Saddle Mountains Basalt contain ground water that is suitable without treatment for human consumption and crop irrigation (see Subsection 6.3.1.1.9). It is primarily for this reason that the potentially adverse condition is present at the reference repository location.

The Columbia Plateau is not part of a known metalliferous or petroliferous geologic province (GG/GLA, 1981), although the Columbia Plateau may contain natural gas resources. There are indications of natural gas in the basalt sequence or from beneath the basalts in the reference repository location, although not actually identified, that could be present in economically extractable quantities. This is a secondary reason for taking a position of present for this potentially adverse condition. Small quantities of natural gas (methane) are present in ground water in the reference repository location and are not uncommonly encountered during drilling of wells in the Columbia Plateau (see McFarland, 1983). The source of the natural gas may be interbeds within the basalt sequence or a sedimentary rock sequence beneath the basalts. The best drill sites for hydrocarbon exploration are expected to be within the closure of anticlinal ridges of the Yakima Fold Belt. The potential for extracting hydrocarbons from beneath the reference repository location is, at best, speculative. However, because little information is available on the structure and stratigraphy of the geologic units beneath the basalts, uncertainties exist regarding unidentified quantities of economically extractable natural gas deep beneath the reference repository location.

6.3.1.8.6 Potentially adverse condition

"(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation."

There is no evidence of subsurface mining or extraction activities for resources in the reference repository location. Therefore, this potentially adverse condition is not present at the reference repository location.

The only evidence of mining or extraction for natural resources within the reference repository location is the existence of sand and gravel quarries. No subsurface mining or extraction for resources has taken place within the reference repository location. The quarries are excavated pits that generally average less than 18 meters (60 feet) in depth. Quarry operations at this depth will not affect waste isolation or containment in a repository situated 869 to 943 meters (2,850 to 3,093 feet) below the ground surface.

6.3.1.8.7 Potentially adverse condition

"(3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation."

This potentially adverse condition is not present at the reference repository location, since boreholes for other than the purpose of repository site evaluation are significantly shallower than the Cohassett flow and would not affect waste isolation or containment.

Boreholes drilled in the reference repository location for purposes other than repository site evaluation were not deeper than the top of the basalt sequence, except for a few borings drilled into the upper part of the Saddle Mountains Basalt. These boreholes are used for measuring water levels and collecting ground-water samples as part of the Hanford Site shallow ground-water monitoring programs. The only boreholes penetrating the Wanapum and Grande Ronde Basalts in the reference repository location and vicinity would have a potential of affecting waste containment and isolation. These boreholes were drilled for repository site evaluation.

6.3.1.8.8 Potentially adverse condition

"(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources."

The reference repository location contains low-value material (gas, rocks, minerals, or petroleum) common in the rest of the Columbia Plateau. This potentially adverse condition is not present at the reference repository location.

The area within 100 kilometers (62 miles) of the reference repository location is not part of a known metalliferous or petroliferous geologic province (see Subsection 6.3.1.8 3). There is no evidence to suggest significant concentrations of any naturally occurring mineral or rock that is unique to the reference repository location. Common construction materials (sand, gravel, and basalt) are found within the reference repository location; however, these materials are readily available outside the site area. Exploration for natural gas is being conducted on the Columbia Plateau (see Subsection 6.3.1.8.3). Exploratory drilling has been targeted for anticlinal ridges, not in structural depressions such as the Cold Creek syncline. The anticlinal ridge nearest the reference repository location that is likely to be a target for natural gas exploration is Yakima Ridge, located 3 kilometers (2 miles) to the west.

6.3.1.8.9 Potentially adverse condition

"(5) Potential for foreseeable human activities--such as ground-water withdrawal, extensive irrigation subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments--that could adversely change portions of the ground-water flow system important to waste isolation."

There is a potential for foreseeable human activities that could change some hydraulic properties of the ground-water system important to waste isolation. Principally, these activities include ground-water withdrawal, water application, and deep fluid injection. Such activities could change hydraulic gradients that are the driving forces for ground-water movement and radionuclide transport from the repository. Even though the potential for such activities to impact waste isolation adversely is considered low, this potentially adverse condition is conservatively assumed to be present at the reference repository location.

For human activities to affect waste isolation adversely, those characteristics of the ground-water system controlling radionuclide releases to the accessible environment must change. The rock geochemistry and deep-water chemistry, which appear favorable to radionuclide adsorption (see Subsection 6.3.1.2), will not change in response to human activities; neither will the basic geologic setting of the repository environment. This leaves the hydraulic properties of the basalt, specifically the hydraulic head distributions, to be potentially altered in response to future human activities.

At the reference repository location, that portion of the ground-water system important to isolation (i.e., along likely flow paths for radionuclide) is the deep Wanapum and Grande Ronde Basalts. The hydraulic characteristics of this system are not expected to change adversely for the following reasons.

- A sufficient supply of shallow water is available from the Columbia River, the shallow unconfined aquifer, and the upper confined aquifers for the foreseeable future. Therefore, deeper exploration would be unnecessary. In addition, studies have indicated (see Section 3.3.2) that the Grande Ronde Basalts form a series of generally low-permeability aquitards separating even lower permeability aquicludes. Information does not suggest these deep basalts, in the vicinity of the reference repository location, have a large potential for future ground-water withdrawal.

- The deep ground water in the Wanpum and Grande Ronde Basalts is not suitable for human consumption or crop irrigation without treatment (see Subsection 6.3.1.1.9). Poor water quality results from high concentrations of naturally occurring fluoride, boron, and sodium. The sodium adsorption ratios and salinity of these waters also impact their suitability for crop irrigation.

- Subsurface fluid injection could occur at or near the reference repository location if economic quantities of natural gas are discovered. Fluid injection for resource recovery is not expected to affect isolation because such injection would be far beneath (approximately 3,000 meters (10,000 feet)) the Cohassett flow. This separation places several tens of individual basalt flows between the injected fluids and the Cohassett flow.

- Military activities (other than the present 200 Areas defense waste-management facilities), underground pump storage, or construction of large-scale surface-water impoundments are not expected to be developed at the reference repository location. Past 200 Areas operations have impacted water quality and recharge of the local unconfined aquifer and shallow confined aquifers. Present or future operations are not expected to impact the deep ground-water system.

- It is expected that any future intruders would detect or be warned by passive institutional controls of the potential danger of exploration, excavation, or water withdrawal activities in the controlled area.

- The controlled area for the reference repository location is bordered by geologic structures that appear to isolate the site from hydraulic effects of irrigation off the Hanford Site. These structures include the Umtanum Ridge-Gable Mountain structure to the north, Cold Creek barrier to the west, and Rattlesnake Mountain plus Yakima Ridge to the south. Therefore, water withdrawal or application away from the immediate vicinity of the reference repository location is not likely to have a significant effect on site hydraulic characteristics.

6.3.1.8.10 Disqualifying condition

"A site shall be disqualified if--

"(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment. . ."

Records do not reveal any major previous exploration, mining, or extraction of resources in the reference repository location. This data base is not expected to change. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1). Little or no uncertainty is involved in making this determination.

The Hanford Site has a limited history of commercial, mineral, or ground-water exploration and extraction activities. No known mining, exploration, or extraction activities have occurred at the reference repository location other than surface extraction of sand, gravel, and basalt. Surface mining activities have not created significant pathways between the projected repository underground layout area and the accessible environment.

Detailed information on ground-water use within the Pasco Basin and the surrounding region has been summarized in a report by the U.S. Department of Energy (DOE, 1982e, pp. 5.1 through 5.189). Primarily, water demand in the Pasco Basin is satisfied by supplies from surface-water sources. Ground-water withdrawals comprise a small percentage of the total water demand. Approximately 50 percent of the water wells within the Columbia Plateau and the Pasco Basin are used for households, and most of the wells are relatively shallow (less than 150 meters (500 feet) deep). Agricultural use represents one-third of the total number of wells, and industrial is a small percentage of the total number (see Section 2.1.4 and Subsection 3.3.1.5).

Within the Pasco Basin, in the upper Cold Creek Valley where irrigated agriculture activities have been expanding, the average water-level elevation within the Priest Rapids Member of the Wanapum Basalt has declined approximately 10 meters (33 feet) over the past few years. However, these activities are greater than 5 kilometers (3 miles) away from the reference repository location, and the upper Cold Creek Valley may be isolated hydrologically from the projected repository underground layout area (i.e., the Cold Creek barrier; see Fig. 2-1).

6.3.1.8.11 Disqualifying condition

"A site shall be disqualified if--

"(2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation."

Possible future activities to recover presently valuable natural mineral resources (high unit value or oil and gas) outside the controlled area are not expected to lead to an inadvertent loss of waste isolation. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Two valuable natural mineral resources (gold placers and natural gas) have been recovered from outside the controlled area, but are not known to be present in the reference repository location. Small gold placers located on gravel bars along the Columbia River were worked during the Great Depression. Possible future mining of gold placers could also be conducted in surficial deposits that lie above the Columbia River Basalt Group. These possible mining activities would not be expected to effect the isolation of radioactive waste in the reference repository location.

Two potential sources of natural gas in the vicinity of the reference repository location are (1) within the Columbia River Basalt Group and (2) beneath it. A small, depleted, low-pressure, natural gas field in basalt that was in production from 1929 to 1941 is present on Rattlesnake Mountain at the southern edge of the Hanford Site (11 kilometers (7 miles) south of the reference repository location). At current economics, the old Rattlesnake Hills gas field is noncommercial. If gas fields were to exist elsewhere within the basalts of the Columbia Plateau, they would be associated with anticlinal ridges of the Yakima Fold Belt outside the Hanford Site and, like the Rattlesnake Hills gas field, would be small and low in pressure. This is because the hydrocarbons would migrate to the anticlinal ridges, which could provide the structural traps. Activities used to recover gas from these fields would not be expected to affect waste isolation in the reference repository location on the Hanford Site.

The Yakima Fold Belt of the Columbia Plateau is being explored for its natural gas potential by Shell Oil Company and Atlantic Richfield Company. Four wells have been completed and tested. All wells were deemed noncommercial, even the natural gas that was recovered from the wells. The primary exploration horizon is the sedimentary rocks below the Columbia River Basalt Group.

Activities associated with the recovery of natural gas from wells drilled on anticlinal ridges of the Yakima Fold Belt and into sedimentary rocks at depths of perhaps greater than 3,000 meters (10,000 feet) below the repository depth would not be expected to affect adversely the ground-water flow system important to waste isolation in the reference repository location. The thick basalt sequence between the subbasalt sedimentary rocks and the Cohassett flow is believed to form a series of aquicludes and aquitards. It is considered unlikely that direct communication exists between the ground-water flow system in the subbasalt sedimentary rocks and the ground-water flow system in the upper Grande Ronde Basalt.

6.3.1.8.12 Conclusion on qualifying condition

A final conclusion on the natural resources qualifying condition dealing with human interference cannot be made on the basis of available data. However, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3). The factors that support this finding are listed below.

- Natural resources are scarce at or near the reference repository location, except for sand, gravel, and basalt that have been locally quarried for construction projects. These surficially mined materials are readily available outside the reference repository location.

- As addressed in Subsection 6.3.1.1.9, deep ground waters beneath the reference repository location contain natural chemical constituents that would require removal or treatment before these waters would be suitable for human consumption and (or) crop irrigation.

- Four recently-drilled hydrocarbon exploration wells have been deemed by Shell Oil Company and Atlantic Richfield Company to be noncommercial. Exploration targets are the deep sedimentary horizons (3,658 meters (12,000 feet)) beneath the thick sequence of Columbia River Basalt Group. Exploratory drilling for hydrocarbons in the Columbia Plateau has been associated with anticlinal ridges. No exploratory drilling for hydrocarbons in the central Columbia Plateau has occurred in synclinal areas.

- Any intruders would be expected to detect or be warned by passive institutional controls of the potential dangers of exploration, excavation, or ground-water withdrawal activities in the controlled area.

The principal uncertainties in the human interference qualifying condition are related to hydrocarbon exploration, although some uncertainty exists with the effects of ground-water withdrawal. It is not known if hydrocarbons in economical quantities are present beneath the thick sequence of basalt of the Columbia Plateau in the vicinity of the reference repository location. The presence of hydrocarbons from beneath the basalts is, at best, speculative.

6.3.2 POSTCLOSURE SYSTEM GUIDELINES (Section 960.4-1)

6.3.2.1 Qualifying condition

"The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see Appendix I of this Part)."

6.3.2.2 Evaluation process

The postclosure system guideline defines general requirements for the performance for the entire waste-disposal system after the repository has been closed. These performance requirements are based generally on the objective of protecting the health and safety of the public until the radioactivity of the waste has decreased to safe levels (i.e., 10,000 years) and specifically on the requirements of 40 CFR 191 (EPA, 1985) and 10 CFR 60 (NRC, 1985a).

The waste-disposal system consists of a natural barrier subsystem (extending from the waste package and mined repository to the accessible environment) and the engineered barrier subsystems (the waste package and the mined repository). The role of engineered barriers as part of the total waste-disposal system is recognized by the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission. These organizations have established specific performance requirements or objectives in 40 CFR 191 (EPA, 1985) and 10 CFR 60 (NRC, 1985a), respectively. However, the objective of the General Siting Guidelines (DOE, 1984a) is to assure the selection of a site that is suitable for waste isolation. To focus on the suitability of the specific site, the geohydrological and geochemical characteristics of the site subsystem have been evaluated independently from any engineered subsystems; engineered barriers have also been considered to assess the effectiveness of the overall system (Section 6.4.2). At this stage of site investigations, the data that have been collected and analyzed are insufficient for assessing the performance of the total waste-disposal system, its subsystems, and components or the uncertainties associated with each component. Such an assessment would be conducted after site characterization and the final design of the repository have been completed. Therefore, final conclusions about the ability of the site to comply with the postclosure system guideline are neither possible nor expected at present. However, it is possible to make preliminary judgments about the ability of the site to comply with the system guideline.

Compliance with this qualifying condition will be assessed using analyses of radionuclide transport from the proposed repository to the accessible environment based on laboratory, field, and literature data. The essential elements of such analyses are listed below.

- A conceptual model of the engineered barrier subsystem and the host rock setting that depicts features, conditions, and processes important to repository system performance.

- A numerical model or suite of submodels that represent the conceptual model.

- A representative data base, including uncertainty distributions necessary for application of the numerical models.

- An understanding of the nature, effects, and likelihood of disruptive events and processes that might significantly alter the performance of the repository system.

Development and application of the assessment methodology and data base needed for demonstration of compliance with the qualifying condition is ongoing. The calculation of ground-water travel times is an important aspect for demonstration of compliance. Based on available data and preliminary interpretation of the ground-water system, ground-water travel times to the accessible environment from the repository are likely to be greater than 1,000 years (see Subsection 6.3.1.1.11). Radionuclide transport is another important factor in determining compliance with this guideline. An initial analysis of projected cumulative release at the accessible environment, based on limited laboratory and field data, for the 10,000 years after repository closure suggests that the probability of meeting the standard specified in 40 CFR 191 (EPA, 1985) is high (Section 6.4.2). For this analysis, no credit was taken for retardation of ground-water or radionuclide movement in the Cohassett flow interior. It appears that iodine-129 and carbon-14 (neither of which appear to be sorbed on packing materials or pathway minerals) are the only radionuclides with the potential for reaching the accessible environment in 10,000 years (Subsection 6.4.2.6.2).

6.3.2.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for the postclosure system guideline cannot be made based on available data. However, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3). Factors that support this preliminary finding are summarized below.

- A geohydrologic setting in which preemplacement ground-water travel time to the accessible environment is likely to exceed 1,000 years.
- A geohydrologic setting in which radionuclide releases to the accessible environment is not likely to exceed U.S. Environmental Protection Agency limits for 10,000 years (EPA, 1985).
- A reducing geochemical environment that is likely to inhibit corrosion of metal containers, suppress the dissolution of most radionuclides in the waste, and retard the movement of radionuclides (relative to the movement of water) along pathways to the accessible environment.
- A system that is unlikely to be altered unfavorably by construction of the repository or the presence of radioactive waste or by natural or human-induced events or processes.

The principal uncertainties related to the factors that support the preliminary finding are the validity of the conceptual geohydrologic model utilized for radionuclide transport analysis and the values of key geohydrologic and geochemical parameters. Of primary importance are definition or identification of the following:

- Vertical conductivity of basalt flow interiors.
- Discrete geologic features that might allow significant vertical transport of radionuclides.

- Element solubilities in the prevailing environment.
- Retardation mechanisms along radionuclide transport pathways.

6.3.3 PRECLOSURE TECHNICAL GUIDELINES

6.3.3.1 Surface characteristics (Section 960.5-2-8)

6.3.3.1.1 Qualifying condition

"The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in Section 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure."

6.3.3.1.2 Evaluation process

The reference repository location is situated in an area of low relief approximately midway along the length of the Cold Creek Valley. See Figure 3-15 for a topographic map of the reference repository location.

Section 3.3.1 details many specifics regarding the flood history and flood potential of the Columbia and Yakima Rivers under natural and dam-failure conditions. In addition, it addresses the flash-flood potential for the Cold Creek watershed in which the reference repository location lies. In summary, the land-surface elevation within the reference repository location ranges between 190 and 245 meters (625 and 800 feet) above mean sea level. This topographic relief effectively protects the location from conceivable flood scenarios for the Columbia and Yakima Rivers, including natural flooding and dam-breach scenarios.

A potential for flash flooding of limited extent exists within the reference repository location. Analyses suggest that approximately 9 square kilometers (3.5 square miles) of the reference repository location might be inundated by a probable maximum flood in the Cold Creek watershed. Portions of this flood could extend into the area considered for repository support facilities on the surface (see Fig. 3-29). Using conservative data inputs, a maximum flood depth of approximately 2.3 meters (7.7 feet) was calculated along the southwestern border of the reference repository location (Skaggs and Walters, 1981). The elevation of the valley floor is approximately 195 meters (640 feet) along the southwest corner of the reference repository location. Theoretically, the recurrence interval of a probable maximum flood cannot be defined. The duration of this flood would be short. As detailed in Subsection 6.3.1.5.2, the reference repository location surface has undergone only minor, local, fluvial and eolian reworking over the past 13,000 years.

6.3.3.1.3 Favorable condition

"(1) Generally flat terrain."

This favorable condition is present at the reference repository location, since the site is located on generally flat terrain.

The reference repository location is generally flat, except for one area of moderate relief in the northwestern corner (see Fig. 3-5).

6.3.3.1.4 Favorable condition

"(2) Generally well-drained terrain."

This favorable condition is present at the reference repository location, since the site is located on well-drained terrain.

The lack of surface runoff features suggests the relatively coarse surficial sediments are effective in keeping the surface well drained and preventing surface runoff from developing in the reference repository location north and east of the Cold Creek flood plain. See Subsection 3.3.1.3 regarding the historical and projected flooding potential of the Hanford Site and reference repository location. According to Skaggs and Walters (1981), there is a potential for short-term surface flooding of Cold Creek over the repository support facilities on the surface. Most of the reference repository location lies within the drainage of Cold Creek Valley.

6.3.3.1.5 Potentially adverse condition

"Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository."

A potential for flash flooding of limited extent exists within the reference repository location. Therefore, this potentially adverse condition is considered present at the reference repository location

Elevations within the reference repository location range between 190 and 245 meters (625 and 800 feet) above mean sea level. These elevations effectively protect the reference repository location from conceivable flood scenarios for the Columbia and Yakima Rivers, including natural flooding and dam-breach or -failure scenarios (see Subsection 3.3.1.3).

A potential for flash flooding of limited extent exists within the reference repository location (see Subsections 3.3.1.3.5 and 6.3.3.1.2). This phenomenon would primarily occur in the southwestern portion of the reference repository location along the drainage channel of Cold Creek Valley. Water depth in this area could reach approximately 2.3 meter (7.7 feet) above the valley floor during a probable maximum flood. The fringe of these waters could reach areas considered for repository support facilities on the surface.

6.3.3.1.6 Conclusion on qualifying condition

The evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (level 3). The following factors support this finding.

- The reference repository location is generally flat.
- The terrain is well drained and is within an arid climate.

Little or no uncertainty is associated with these factors.

6.3.3.2 Rock characteristics (Section 960.5-2-9)

6.3.3.2.1 Qualifying condition

"The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met."

6.3.3.2.2 Evaluation process

Evaluation of the rock characteristics preclosure performance has been based on (1) geomechanical field, laboratory, and numerical studies, (2) conceptual designs, and (3) evaluation of past construction experience in hard rock. The results of these studies have been used in conjunction with geologic and hydrologic data to evaluate the suitability of rock characteristics at the reference repository location as a potentially acceptable site for a nuclear waste repository and to assess the performance of a repository. The data, data uncertainties, assumptions, and analyses used to characterize the rock mass behavior, relative to the repository preclosure performance, are presented in the favorable and potentially adverse conditions. Much of the data and analyses referenced here has been summarized in the site-characterization report (DOE, 1982e) and repository horizon-identification report (Long and WCC, 1984).

6.3.3.2.3 Favorable condition

"(1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility."

This favorable condition is present in the reference repository location. The Cohassett flow would provide a sufficiently thick and laterally extensive host rock to allow significant flexibility in selecting the depth, configuration, and location and to allow for the construction, operation, and closure of a repository without causing undue hazard to personnel. The Cohassett flow interior appears to meet these requirements and, therefore, has been selected as the host rock horizon.

Preclosure host rock thickness and lateral extent necessary for repository development are largely dependent on the functional (size) requirements for a repository. Areal requirements for a repository in the current design concept (see Subsection 5.1.3.2) were based on the need to store 70,000 metric tons (77,000 tons) of heavy metal. Additional factors that influence the size of the repository are waste type and age, rock temperature limits, and rock stress limits. The repository underground layout study (RKE/PB, 1984b, preliminary drawings 1 through 13) considered storage requirements and in situ stress magnitudes determined that a 1,900- by 4,150-meter (6,200- by 13,600-foot) or 800-hectare (2,000-acre) repository underground layout would be required.

Repository size requirements vary, depending on the magnitude of the in situ stress. The following in situ stress magnitudes were used in the repository underground layout study: Vertical stress of 23 megapascals (3,350 pound-force per square inch), minimum horizontal stress of 33 megapascals (4,800 pound-force per square inch), and maximum horizontal stress of 58 megapascals (8,400 pound-force per square inch). Due to the uncertainty inherent in measuring in situ stresses from hydrofracturing techniques in surface boreholes, additional calculations using conservative stress magnitudes were made. Use of a stress level two standard deviations higher than that used in the design resulted in the following stress magnitudes: Vertical stress of 23 megapascals (3,350 pound-force per square inch), minimum horizontal stress of 37 megapascals (5,410 pound-force per square inch), and maximum horizontal stress of 73 megapascals (10,600 pound-force per square inch). This could result in a 3,300- by 4,150-meter (10,800- by 13,600-foot) or 1,370-hectare (3,380-acre) subsurface repository. This expanded repository size, which is only 33 percent of the reference repository location, still allows significant lateral flexibility in siting the repository underground layout area summarized in Table 6-11.

Table 6-11. Comparison of repository size requirements for different in situ stress magnitudes within the reference repository location

In situ stress			
Vertical, MPa (lbf/in^2)	Minimum horizontal, MPa (lbf/in^2)	Maximum horizontal, MPa (lbf/in^2)	Repository size requirements, ha (acres)[a]
23 (3,350)	33[b] (4,800)	58[b] (8,400)	800 (2,000)
23 (3,350)	37[c] (5,410)	73[c] (10,600)	1,370 (3,380)

[a]Reference repository location is 4,050 hectares (10,000 acres).
[b]Mean horizontal stress.
[c]Mean horizontal stress plus two standard deviations.

The lateral extent of the Cohassett flow is apparent from the isopach map (see Fig. 3-11, 3-13 through 3-15). When considering these data plus the 4,050-hectare (10,000-acre) size of the reference repository location, there is more than adequate lateral flexibility to locate the proposed 800-hectare (2,000-acre) repository underground layout area within the reference repository location. There is also sufficient lateral extent in the reference repository location to accommodate geologic anomalies and higher in situ stress than the values used in the current design concept.

Repository room height requirements would vary from 4.3 meters (14 feet) in the shaft pillar area to 3 meters (10 feet) in the waste panel area. A conservative estimate of the required Cohassett flow interior thickness in the shaft pillar area is 21 meters (70 feet). This minimum thickness was assumed by considering stress redistribution around an excavated opening. Most of the stress redistribution occurs within one radius from the excavation (within 1 to 2 meters (3 to 6 feet)). To be conservative, two room radii are included in the minimum thickness criterion as shown in Figure 6-7. In the waste panel area where thermal-induced stresses would be greater, a minimum thickness criterion of three room radii above and below the emplacement room was assumed, resulting in a 21-meter (70-foot) minimum thickness criterion (see Fig. 6-7). The minimum thickness criterion described above is consistent with and less than the minimum thickness criterion of 27 meters (89 feet) established for postclosure rock characteristics (see Subsection 6.3.1.3.3; Fig. 6-5). Drift grades are currently designed at a uniform 0.5-percent grade; however, the repository design would be flexible enough so that waste panel drift grades may be altered enabling the slope of the waste panels to be approximately equal to the slope of the flow.

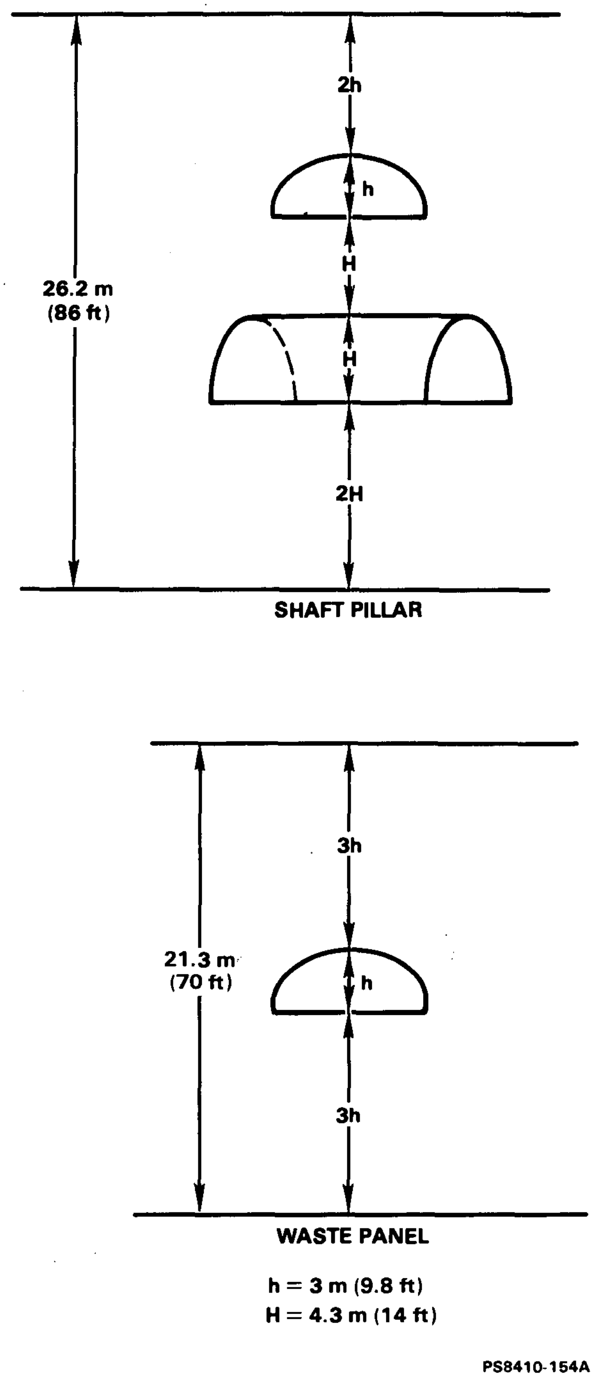


Figure 6-7. Preclosure repository thickness criteria. (For additional thickness criteria, see Fig. 6-5.)

Total flow thickness and flow interior thickness vary with lateral position and are difficult to quantify with a limited number of boreholes (see Fig. 3-11). Exposure of the thick flows in the Grande Ronde Basalt in the reference repository location can be observed in outcrops located 29 to 40 kilometers (18 to 25 miles) from the reference repository location. These exposures indicate the potential variability of flow thickness and flow interior thickness that may be expected of the Cohassett flow. The Cohassett flow interior thickness shows the least variability of the four proposed candidate horizons (Long and WCC, 1984, pp. I-53 through I-67).

Regional thickness data obtained from boreholes and outcrops throughout the northern and central Pasco Basin are presented in Table 6-12. Thickness data for the entire northern and central Pasco Basin are presented for the purpose of showing the laterally extensive nature of the four horizons considered as candidate horizons. The data indicate the thickness of the flow interior below the flow top in each of the four flows. Borehole and outcrop locations are shown in Figure 3-11. The data in Table 6-12 are further subdivided into three groups. The first group consists of thickness data from throughout the northern and central Pasco Basin, the second group consists of thickness data from boreholes within 5 kilometers (3 miles) of the reference repository location, and the third group of data is from within the reference repository location. The last group of data is more representative of the thicknesses that may be expected in the reference repository location, in that this information is within the Cold Creek syncline structure. The mean and standard deviation of the three groupings of data for the Grande Ronde Basalt flows are listed in Table 6-13.

Further statistical analysis of these data is not warranted given the wide areal distribution of data. The data indicate that the Cohassett flow is sufficiently thick to provide flexibility in selecting the depth and grade for the repository underground layout area. The Cohassett flow provides three times the thickness (21 meters (70 feet)) necessary to construct the repository emplacement rooms within the flow. Variability in the thickness of the flow and the rock mass quality within the dense interior can be expected, but is difficult to quantify without subsurface access or extensive drilling.

In defining the thickness requirements for the Cohassett flow, the need to excavate through intraflow features must be addressed. These features are discussed in detail in Subsections 3.2.2.3 and 6.3.3.2.9. One specific consideration has been the vesicular zone, which is generally present within the interior of the Cohassett flow. Opening stability within this zone is expected to require no additional support beyond that expected for the remainder of the flow interior (Barton, 1986). However, the zone does exhibit differing physical properties than those expected of the rock mass in the dense flow interior. Test results from the limited number of vesicular Cohassett flow samples available are shown in Table 6-14.

Table 6-12. Thickness data for the Cohassett flow relative to other thick Grande Ronde Basalt flows

Group	Borehole or measured section	Thickness, m			
		Rocky Coulee flow	Cohassett flow	McCoy Canyon flow	Umtanum flow
Northern and central Pasco Basin[a]	DDH-3	33.2	39.6	16.2	71.9
	DC-15	24.1	41.5	21.3	45.3
	DC-8	29.6	46.0	30.6	46.9
	DC-12	39.9	57.0	24.5	55.3
	DC-6	19.8	65.1	38.7	59.4
	DH-4	9.4	52.1	24.1	26.8
	DH-5	42.7	61.0	48.8	54.9
	DC-14	44.5	62.5	35.4	19.5
	RSH-1	28.0	58.8	27.1	51.2
	Emerson Nipple	37.8	71.6	40.8	37.8
	Sentinel Gap	37.8	64.3	55.5	76.8
Reference repository location +5 km (3 mi)[b]	DC-2	25.9	78.3	22.0	50.9
	DC-19C	27.7	42.7	27.4	16.8
	McGee Well	20.4	53.3	26.8	36.0
Reference repository location	RRL-2	46.6	74.7	31.4	25.3
	RRL-6	86.2	67.4	30.5	41.7
	RRL-14	30.5	62.2	33.2	39.0
	DC-3	36.3	73.5	26.2	47.2
	DC-4	27.1	75.0	33.5	45.5
	DC-16A	25.7	71.0	22.6	47.9
	DC-20C	29.0	75.6	32.3	29.0
	DC-22C	43.3	73.8	23.2	23.8

NOTE: 1 meter = 3.28 feet.
[a]Group includes all boreholes and measured sections in table.
[b]Includes all reference repository location boreholes.

Table 6-13. Mean interior thickness and standard deviation for four Grande Ronde Basalt flows

Statistical parameter	Northern and Central Pasco Basin	Reference repository location +5 km (3 mi)	Reference repository location
Rocky Coulee flow			
Mean thickness, m	32.1	32.6	35.6
Standard deviation, m	9.7	9.1	8.7
Cohassett flow			
Mean thickness, m	62.1	68.0	71.7
Standard deviation, m	12.0	11.0	4.7
McCoy Canyon flow			
Mean thickness, m	30.6	28.1	29.1
Standard deviation, m	9.2	4.3	4.5
Umtanum flow			
Mean thickness, m	43.1	36.6	37.4
Standard deviation, m	15.8	11.4	9.9

NOTE: 1 meter = 3.28 feet; one deviation equals 1 .

Table 6-14. Rock mechanics characteristics of the Cohassett flow vesicular zone

Statistical parameter	Static Young's modulus, GPa (10^6 lbf/in^2) (taken from 4 samples)	Uniaxial compressive strength, MPa (10^3 lbf/in^2) (taken from 9 samples)	Bulk density, g/cm^3 (lb/ft^3) (taken from 20 samples)
Mean	51.44 (7.4)	163.63 (23.5)	2.62 (163.5)
Standard deviation	6.39 (0.92)	63.34 (9.1)	0.09 (5.6)
80% confidence interval	45.4 to 57.5 (6.5 to 8.3)	133.2 to 194.0 (19.2 to 27.9)	2.59 to 2.65 (161.6 to 165.4)

NOTE: Taken from Rockwell (1983c, p. 30).

Compensating factors may influence the significance of the vesicular zone to repository construction. The in situ stresses acting on the vesicular zone rock mass are expected to be lower than that expected within the dense flow interior. For example, the degree of core disking is not as pronounced within the vesicular portions of the flow interior. However, no in situ stress determinations are available. Also, the strength of the vesicular zone is less than the dense portion of the flow interior (approximately 56 percent of the intact entablature strength). The modulus of elasticity also varies to a lesser extent (approximately 68 percent of the intact entablature static modulus). The reduction of strength or modulus of the vesicular samples cannot be explained by the reduction of the surface area of the rock sample due to vesicularity. The reduction in modulus is expected to compensate partially for the lower strength of the vesicular zone. Additional investigations of the vesicular zone rock mass properties and state of stress are warranted before the utility of the vesicular zone for emplacement of waste can be established with confidence. The current design concept does not require or assume emplacement of waste within the vesicular zone. Excavation within this zone is not expected to result in a significant increase in support requirements (Subsection 6.3.3.2.4; Barton, 1986).

6.3.3.2.4 Favorable condition

"(2) A host rock with characteristics that would require minimal or no artifical support for underground openings to ensure safe repository construction, operation, and closure."

Preliminary evaluations of rock-support requirements based on empirical methods and conservative judgment suggest that artifical support would be required for repository construction, operation, and closure. The artificial support thought to be needed (rock bolts and shotcrete) is not considered minimal. However, such support is not considered unusual in comparison to other underground mining operations. In addition, there is uncertainty in the effect of thermal-induced stresses in the emplacement rooms relative to the need for artificial support. Therefore, this favorable condition is not considered present in the reference repository location.

Historically, underground openings were supported by timber posts, cribs, or steel sets. Modern practice in hard-rock excavation is to utilize the inherent strength available in the rock mass (even if fractured) through the use of rock bolts, shotcrete, welded wire mesh, or a combination of these devices. In some poor rock conditions, these may be supplemented by cast-in-place concrete with or without steel sets. Cast-in-place concrete and steel set support systems serve as passive restraint to the rock and do not utilize the inherent rock mass strength as well as the more modern techniques. Rock bolts support loose blocks in the roof or wall, but their main function is to extend the rock mass strength by applying a small confinement pressure to the jointed rock mass around the opening, thus limiting excessive deformations. This confinement pressure limits deformation and enhances block interlocking and normal stress development along the joint surfaces, resulting in greater joint shear strengths and higher rock mass strength.

Subsurface excavation instabilities generally can be categorized as structurally controlled, structurally controlled stress induced, or stress induced. Structurally controlled instabilities are most common in excavations of low to moderate stress environments at depths of less than 500 to 1,000 meters (1,640 to 3,280 feet) (Hoek, 1981). This type of instability is generally associated with blocky, jointed, or bedded rock that has kinematic potential (i.e., the ability to develop gravity-assisted movement or fallout from the roof or sidewalls). Therefore, this type of instability is dependent on rock characteristics such as joint strength, joint condition (e.g., infilling, roughness), and joint orientation, persistence, and spacing. Other factors influencing structurally controlled instabilities are the excavation shape, size, and orientation.

Structurally controlled stress-induced and stress-induced opening instabilities develop under conditions where high stress is present around the openings. These failures are the most likely type that could be encountered at the reference repository location. In a structurally controlled stress-induced opening instability, rock mass failure develops primarily along an unfavorably oriented discontinuity and is dependent on the presence of such discontinuities. The strength of the intact rock is an important factor in stress-induced instabilities, since intact rock must be fractured for the excavation instability to develop. Examples of stress-induced instabilities include dynamic failures such as rock bursts.

The potential for mild rock bursts cannot be discounted and is addressed in the disqualifying condition (Subsection 6.3.3.2.10). However, the type of rock burst expected (Blake, 1984) in the low-extraction ratio excavation planned for the repository is described as spalling or slabbing, and affects a small volume of rock. The type of event can be controlled by rock bolts with enlarged bearing plates (Barton, 1986, p. 81; Myrvang and Grimstad, 1983, p. 136), bolts applied immediately after excavation (Saito et al., 1983), yielding bolts (Ortlepp, 1970, p. 197), and (or) fiber-reinforced shotcrete (Barton, 1986, p. 85). All these support categories are within the range of the recommended support suggested by Barton (1986) and Voss (1984) using rock mass classification systems. Hence, excessive support is not considered necessary to assure safe repository construction, operation, and closure.

Common methods for evaluating support requirements can be categorized as empirical, observational, and numerical. The most commonly used method of providing preliminary evaluations of excavation support requirements is the empirical method, with numerical and observational methods used as verification. Numerical methods are not always reliable due to the difficulty in modeling the rock-structure interaction and estimating the appropriate rock mass strength and deformation properties. The use of observational methods is not possible until an excavation begins.

The design of underground structures in fractured rock commonly begins with the use of one or more classification schemes developed from compilation of case histories. Empirical methods have been developed from those classification schemes to estimate rock-support or reinforcement requirements based on geologic, engineering, and design data. The two most commonly used classification systems are the rock quality system developed by Barton et al. (1974) and the geomechanics rock mass rating system developed by Bieniawski (1973, 1976, 1979). These systems have been used to classify the rock mass quality of the Cohassett flow interior and to estimate the rock-support requirements that might be expected. Using the rock quality system, the rock mass quality of the Cohassett flow interior was classified as very poor to fair. With the geomechanics rock mass rating system, the same basalt rock mass is classified as fair to good. The discrepancy between these two systems is due to differing definitions of what constitutes a poor or fair quality rock mass. Both methods, however, result in comparable support recommendations.

Values used in the assessment of the geomechanics rock mass rating system and the rock quality system are given in Tables 6-15 and 6-16, respectively. These methods were applied to excavation in the entablature and colonnade intraflow structures. The rock mass rating system classifies the colonnade higher than the entablature, because of its wider joint spacing and higher rock quality. The rock quality system classifies the entablature higher than the colonnade, because Barton's method places the colonnade into the mild rock burst category. This category requires a higher stress reduction factor for the colonnade.

Table 6-15. Geomechanics classification of repository excavations in the Cohassett flow

Classification parameter	Parameter value				Parameter rating			
	Entablature		Colonnade		Entablature		Colonnade	
	Low	High	Low	High	Low	High	Low	High
Intact rock strength, MPa (lbf/in^2)	282 (40,900)	301 (43,700)	261 (37,900)	315 (45,700)	15	15	15	15
Rock quality designation	30	50	70	90	8	13	13	20
Primary joint spacing,[a] m (ft)	0.037 (0.12)	0.059 (0.19)	0.059[a] (0.19)[a]	0.011[a] (0.364)[a]	5	5	10	10
Primary joint condition	(b)	(b)	(b)	(b)	20	20	20	20
Ground water	(c)	(c)	(c)	(c)	7	7	7	7
Joint orientation adjustment	(d)	(d)	(d)	(d)	-10	-5	-10	-5
Total rock mass rating	NA	NA	NA	NA	45	55	55	67
Class	NA	NA	NA	NA	Fair[e]	Fair[e]	Fair to good[f]	Fair to good[f]

NOTE: After Voss (1984).
NA = not applicable.

[a]After Long and WCC (1984, pp. I-74).

[b]Slightly rough surfaces, separation 0.23 centimeter (0.58 inch), normally weathered less than 1 millimeter (0.04 inch). Updated with data from Lindberg (1986), who noted that 99.4 percent of primary fractures are 100 percent filled with secondary mineral infilling.

[c]Ratio of joint water pressure to maximum stress between 0.1 and 0.2.

[d]Fair to unfavorable.

[e]For fair rock, systematic bolts 3 meters (10 feet) long, spaced 1.5 to 2 meters (5 to 6.6 feet) in the roof and walls with welded wire mesh in the crown; 5 to 10 centimeters (2 to 4 inches) of shotcrete on the roof and 2.5 centimeters (1 inch) on the walls.

[f]For good rock, locally bolts 3 meters (10 feet) long in the roof spaced 2.5 meters (8 feet) apart with occasional welded wire mesh; 5 centimeters (2 inches) of shotcrete where required.

Table 6-16. Rock mass quality classification of repository excavation in the Cohassett flow

Classification parameter	Parameter value		Parameter rating			
			Entablature		Colonnade	
	Entablature	Colonnade	Worst	Best	Worst	Best
Rock quality designation	30 to 50	70 to 90	30	50	70	90
Joint set number	Three joint sets to three joints plus random	Two joint sets plus random to three joint sets	12	9	9	6
Joint roughness number	Smooth to rough, undulating	Slickoxided to smooth, undulating	2	3	1.5	2
Joint alteration number	*	*	4	4	4	4
Joint water reduction factor	Minor to medium inflow or pressure	Minor inflow	0.66	1.0	1.0	1.0
Stress reduction factor (ambient)	High stress, tight structure ($\sigma_C/\sigma_1 = 4.6$)	Mild rock burst ($\sigma_C/\sigma_1 = 4.7$)	1 2	0.5 (roof) 1(wall)	6	4
Stress reduction factor (with thermal loading)	($\sigma_C/\sigma_1 = 2.65$)	($\sigma_C/\sigma_1 = 2.7$)	2 3	1 (roof) 2 (walls)	8	6
Rock quality rating (ambient)	NA	NA	0.8 0.4	8.3 (roof) 4.2 (walls)	0.5	1.9
Rock quality rating (with thermal loading)	NA	NA	0.4 0.3	4.1 (roof) 2.1 (walls)	0.4	1.2
Class (ambient and with thermal loading)	NA	NA	Very poor to fair	Very poor to fair	Very poor to poor	Very poor to poor

NOTE: After Barton (1984). Design ranges are shown; Barton (1984) also states extreme values.
NA = not applicable.

*Softening or low-friction clay mineral coatings--small quantities of swelling clay.

Barton (1986) also applied his system to the expected conditions in the vesicular zone, a zone of the Cohassett flow located approximately one-third of the flow thickness below the flow top (see Subsection 3.2.2.2.3). The vesicular zone is characterized as having similar jointing as the colonnade, but contains vugs and vesicles, some of which are filled with secondary minerals but most (nearly all) are unfilled. In the vesicular zone, the rock strength is lower, with the uniaxial compressive strength approximately 56 percent of the dense interior strength. The in situ stresses are inferred to be lower, because the rock modulus is lower (65 percent of that of the dense interior). Barton (1986) estimated the rock quality rating for the vesicular zone to range from 0.4 to 0.7 under ambient conditions and 0.2 to 0.4 for the thermal range. The resulting support recommendations are indistinguishable from the general range of support recommendations for the remainder of the dense interior. The rock support recommended by Barton does not discriminate between the colonnade and the vesicular zone (Table 6-17).

Table 6-17. Recommended roof reinforcement

Drift type	Portion of Cohassett flow	Bolt spacing, m (ft)	Shotcrete thickness, cm (in.)
Emplacement room, panel entry, and main entry	Colonnade	0.8 (2.6)	5 (2)
	Entablature	—	5 (2)
	Vesicular	0.8 (2.6)	5 (2)[a]
Confinement returns, panel cross cuts, back-reaming drifts, and other panel cross cuts	Colonnade	1.0 (3.3)	2.5 (1)
	Entablature	—	5 (2)
Intersections	Colonnade	0.8 (2.6)	5 (2)
	Entablature	0.8 (2.6)	5 (2)
Any[b]	Flow interior[b]	0.8 (2.6)	20 (8)

NOTE: After Barton (1986, p. 85).
[a]Fiber reinforced.
[b]Extreme local condition.

In the application of the rock quality system, Barton (1986) considered the effect of thermal-induced stresses on the rock-support requirements by increasing the stress reduction factor (see Table 6-16) (Barton, 1986, pp. 69 and 72). Figure 6-8 (Barton, 1986, p. 80) shows the extreme ranges and design ranges selected by Barton to represent the expected conditions throughout the repository. The results of Barton's study indicate that a rock bolt and (or) shotcrete support system would be adequate for all drift types in the repository (support requirements

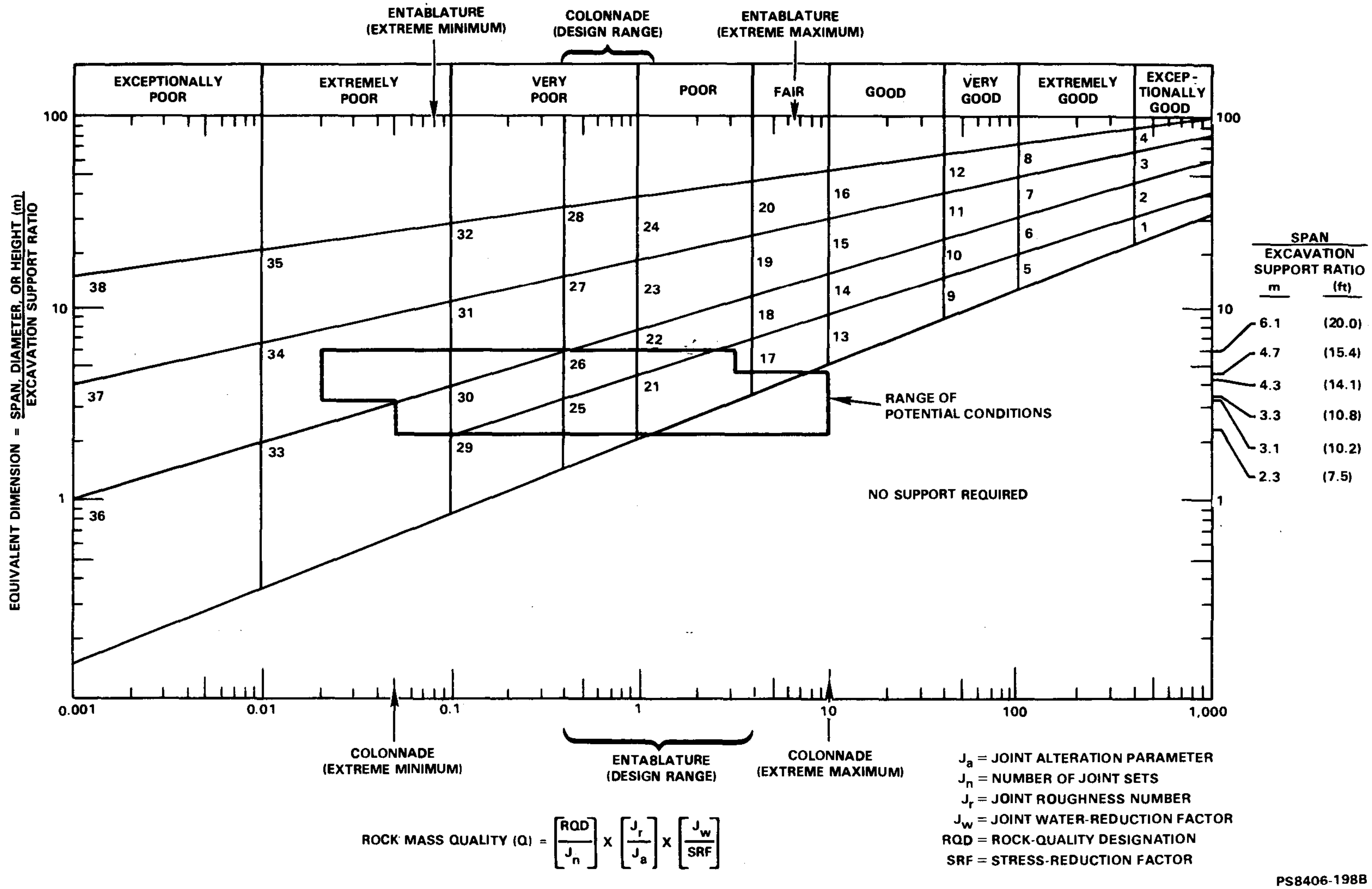


Figure 6-8. Rock-support categories relevant to design range and extreme value qualities for the Cohassett flow (after Barton, 1980).

in each type of drift differ because of variations in such parameters as size, shape, thermal loading, and orientation of drift relation to stress field). The results of the Barton study are shown in Table 6-17.

When the effect of thermal-induced stresses was included in the Barton (1986) analysis, it was found that although the rock quality rating decreased in the waste panel area, the support requirements did not increase significantly because the same support category applied. The shaft pillar area would not experience large temperature increases during thermal loading. Any increase in support requirements in the waste panel due to thermal-induced stresses would be determined in relation to the repository waste panel layout design and container emplacement density.

Other empirical methods, such as those used by Laubscher and Taylor (1976), were also used to evaluate support requirements in the Cohassett flow interior. Laubscher and Taylor modified the geomechanics rock mass rating system (Bieniawski, 1973, 1976, 1979) to account for the influences of weathering, stress state, and blasting method on support requirements in deep underground mining. This method was considered, since most of the case history studies used by Barton and Bieniawski to develop their empirical methods were from depths of less than 1,000 meters (3,280 feet). The stress levels in the Cohassett flow are expected to be greater than most case histories used by Barton and Bieniawski; therefore, the adjustments by Laubscher and Taylor to Bieniawski's geomechanics rock mass rating system could be used to accommodate this higher stress state. These adjustments for high stress states may also be used to evaluate the potential increase in support requirements due to thermal-induced stresses. The empirical method of Laubscher and Taylor results in slightly greater rock-support recommendations than Bieniawski's geomechanics rock mass rating system, but the recommendations are still within the bounds of the previously recommended rock-support requirements.

Caution should be exercised when using these empirical methods to estimate support requirements at the reference repository location. Most of the data base used by Barton and Bieniawski to develop their empirical methods was obtained from shallower depth case history studies with lower stress levels than exist in the Cohassett flow. Therefore, many of these case history studies were probably from structurally controlled instability environments rather than the structurally controlled stress-induced instability environment expected at the reference repository location.

To confirm the empirical method estimates of rock-support requirements, other methods of evaluating rock support (e.g., observational and numerical) would be used. As previously indicated, the observational method would be difficult to utilize or develop until excavations have begun in the Cohassett flow. Other excavation experiences in deep, highly stressed rock conditions are presented in Table 6-18. These case histories can be used to evaluate whether the support system requirements developed for a repository in the Cohassett flow using empirical methods would be sufficient.

Table 6-18. Comparisons of deep, highly stressed excavations

Area	Depth, m (ft)	Stress MPa (lbf/in^2)	Intact unconfined rock strength, MPa (lbf/in^2)	Rock type	Rock-support method
South African gold mines	3,500 (11,500)	68.5 (9,900)	226 (33,000)	Massive quartzites	Timber and steel sets, fully grouted rock bolts with or without welded wire mesh
Kolar gold fields	3,000 (9,800)	Not reported	200 to 420 (29,000 to 60,000)	Quartz ore and metamorphosed igneous rocks (basalt and dolorite)	Elliptical steel sets
Coeur d'Alene mining district	2,400 (7,900)	Up to 100 (14,000)	125 (18,000)	Quartzite and argillite	Fully grouted rock bolts with welded wire mesh and sometimes shotcrete
Michigan copper mining	2,500 (8,200)	Not reported	290 (42,000)	Basalt	Timber sets and rock pack walls*
Hanford Site (Cohassett flow)	910 to 1,020 (3,000 to 3,350)	58 (8,400) (in situ) ~100 (14,000) after thermal load	290 (42,000)	Basalt	Rock bolts and shotcrete recommended

*Mining was completed before development of rock bolt-shotcrete technology.

Numerical methods are not as commonly used as empirical methods, but can be used to confirm the support system requirements established from empirical methods. Reliability in the use of numerical techniques for evaluating support requirements is dependent on how well the model numerically represents the actual physical process being investigated and the rock mass characteristics used in the analysis. Numerical modeling is in progress; however, results are not available.

6.3.3.2.5 Potentially adverse condition

"(1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility."

This potentially adverse condition is not considered present at the reference repository location. The Cohassett flow should provide a thick and laterally extensive host rock to allow flexibility in selecting the configuration and location of an underground facility. Refer to Subsection 6.3.3.2.3 for details relative to this potentially adverse condition.

6.3.3.2.6 Potentially adverse condition

"(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility."

This potentially adverse condition is considered not present in the reference repository location. Based on preliminary investigations, the need for engineering measures beyond reasonably available technology is not expected in the construction of repository shafts and underground facilities.

Geologic and hydrologic site conditions expected at the reference repository location have previously been excavated in other mining or civil project sites, although all conditions may not have been encountered at any one site (see Table 6-18). Because of the long-term requirements for the repository operating life and postclosure constraints, some excavation and support methods may require testing or development. Factors that are or will be addressed are described separately in this subsection for shafts and the underground facility. Some of the constraints to the methods described are nontechnical in nature and related to cost and schedule of repository construction. Excavation and testing during the exploratory shaft program would provide additional information for assessing constructibility (see Subsection 4.1.1.6).

Shaft construction

Various methods of shaft excavation have been considered during development of design concepts for the repository. These methods include ream and slash, drill and blast, and blind-hole drilling.

The ream-and-slash technique is not considered technically feasible at the reference repository location and has been eliminated from consideration. Ground-water inflow and bottom access constraints made this technique unsuitable.

Drill and blast and blind-hole drilling are technically feasible as construction methods for shaft sinking of the diameter and depth expected for a repository. The choice of drill and blast or blind-hole drilling is primarily based on safety, cost, and schedule considerations (RKE/PB, 1984a). A combination of drill and blast and blind-hole drilling, as opposed to each method individually, does not provide a significant cost or schedule advantage. Consequently, this technique was eliminated from consideration.

The drill-and-blast shaft-sinking alternative was considered during development of design concepts. This methodology would have incorporated reasonably available technology, including standard controlled-blasting techniques, mucking procedures, and concrete lining furnished with steel membrane for water tightness. Ground-water control would require drilling of boreholes from the surface, or perhaps from the shaft interior, to allow grouting, freezing, or pumping of the aquifers in advance of excavation. The disadvantages of drill and blast are the technical problems associated with drilling and sealing the small-diameter freeze or grout holes, the long freezing durations required if freezing were to be used to control ground water, and rock wall damage due to blasting.

The blind-hole-drilling method was selected as the preferred shaft-sinking alternative at the reference repository location. This selection was based on the following factors.

- Blind-hole drilling precludes the need for personnel underground until shaft construction is completed, thus providing a significant improvement in safety over other alternatives.

- Blind-hole drilling would produce a minimum disturbance to the rock immediately adjacent to the excavation (Kelsall et al., 1982; Cottam, 1983).

- Blind-hole drilling time is projected to be less than for the other alternatives considered (RKE/PB, 1984a).

- Blind-hole drilling has been previously applied (Hunter, 1983a; Presley, 1981) to overcome similar hydrologic conditions as those expected in the reference repository location.

- Blind-hole drilling would not require drilling or freezing of freeze holes.

Deep, large-diameter shafts have not been previously drilled in the reference repository location and, consequently, site-specific experience does not exist. Preliminary conclusions that blind-hole drilling is feasible, utilizing reasonably available technology, are justified by review of (1) geotechnical information derived from ongoing studies, (2) extensive and successful ongoing (small-diameter) drilling program, and (3) experience gained from other blind-hole-drilling projects where constraints, similar to those which may be encountered during shaft construction at the reference repository location, have been encountered (Table 6-19).

Studies and experience from blind-hole drilling large-diameter shafts at other locations suggest that potentially constraining factors include the following:

- Jamming or lodging of down-hole tools due to slabbing or spalling of the rock wall.
- High inflow of ground water.
- Loss of drilling fluid circulation.
- Capacity of the rig or tools to meet shaft conceptual design dimensions.
- Accurate hole alignment.
- Assurance of adequate rock stability during installation of the liner.
- Prevention of water movement along the shaft wall-liner annulus

Repository siting investigations at the Hanford Site have provided extensive core and rotary drilling experience without major drilling complications or loss of a borehole. Small-diameter boreholes have been drilled in sizes from approximately 8 to 43 centimeters (3 to 17 inches) and to depths exceeding 1,525 meters (5.000 feet). These exploratory boreholes have been drilled in similar geologic and hydrologic conditions as expected in the reference repository location.

Small-diameter boreholes on the Hanford Site have been drilled using the direct circulation method. Direct circulation is the process of pumping drilling fluid down the drill pipe and returning the fluid up the annulus between the drill pipe and the borehole wall. Direct circulation requires large volumes of fluid to be circulated to produce a velocity sufficient to lift drill cuttings from the borehole bottom to the surface. High fluid velocities tend to erode the borehole wall.

Proposed exploratory and repository shafts would be drilled with air-assisted reverse circulation. This method keeps the hole full of drilling fluid by gravity flow. The drilling fluid is returned to the surface

Table 6-19. Evidence of constructibility as compared to planned shaft construction

Location	Drilled in basalt	Spalling, in situ stress	Drilled through aquifers	Compressive strength of rock MPa (lbf/in^2)	Size of hole, cm (in.)	Depth, m (ft)	Average excavation rate, m/d (ft/d) includes lost time	Deviation of alignment (min)	Lined (cased), cm (in.)	Bit type	Cutter type	Circulation system
Planned												
Phase I exploratory shaft, reference repository location, Washington	Yes 40% basalt 30% breccia 30% sand and clay	Expected	Yes	≤345 (≤50,000)	279 (110)	1,052 (3,450)	4.6 (15)	Not yet drilled	Yes 183 (72)	Flat bottom	Tungsten-carbide	Simple reverse
Repository shafts, reference repository location, Washington	Yes	Expected	Yes	≤345 (≤50,000)	457 (180)	1,052 (3,450)	2.4 (8)	Not yet drilled	Yes 366 (144)	Flat bottom	Tungsten-carbide	Simple reverse
Case history												
UA-1, Amchitka, Alaska[a]	Bottom 152 m (500 ft)	Yes	Yes	≤138 (≤20,000)	229 (90)	1,875 (6,150)	5.6 (18.3)	0.67N 0.36E	Yes 137 (54)	Flat bottom	Mill	Simple reverse
UA-4, Amchitka, Alaska[a]	No (andisite)	Yes, amount unknown	Yes	207 (30,000)	305 (120)	1,385 (4,550)	4.8(15.6)	Acceptable	No	Flat bottom	Mill and tungsten-carbide	Simple reverse
UC-4, Nevada Test Site, Nevada[b]	No	Unknown	Yes	≤138 (≤20,000)	305 (120)	1,477 (4,846)	5.9 (19.2)	Unknown	Yes 137 (54)	Flat bottom	Mill	Simple reverse
UC-5, Nevada Test Site, Nevada[b]	No	Unknown	Yes	≤138 (≤20,000)	305 (120)	1,676 (5,500)	5.6	Unknown	No	Flat bottom	Mill	Simple reverse
Agnew, West Australia[c]	No	Yes, amount unknown	No	≤407 (≤59,000)	427 (168)	750 (2,460)	2.1 (7)	Within specifications	No	Flat bottom	Tungsten-carbide	Dual string reverse
Oilshale, Colorado[b]	No	Unknown	Yes	≤103 (≤15,000)	305 (120)	717 (2,352)	6.6 (21.7)	1.68	Yes 244 (96)	Flat bottom	Mill	Dual string reverse
Conoco, New Mexico[d]	No	Unknown	Yes	≤69 (≤10,000)	305 (120)	684 (2,243)	5.2 (16.9)	1.03S	Yes 216 (85)	Flat bottom	Mill	Simple reverse
Waste Isolation Pilot Plant, New Mexico[b]	No	Unknown	Yes	≤35 (≤5,000)	356 (140)	700 (2,298)	6.4 (21)	1.69	Yes 305 (120)	Flat bottom	Mill	Dual string reverse
Bunker Hill, Missouri[e]	No	Unknown	Yes	≤152 (≤22,000)	274 (108)	434 (1,425)	7.0 (23)	Line of sight	Yes 213 (84)	Flat bottom	Mill and tungsten-carbide	Simple reverse
Bougainsville Island, New Zealand[f]	No	Yes 1.85:1	Yes	≤248 (≤36,000)	168 (66)	210 (688)	15.2 (50) reamed	Within specifications	Yes 76 (30)	Tapered reamer	Disk and mill	Simple reverse
Summer Falls, Washington[g]	Yes	No	No	≤241 (≤35,000)	198 (78)	24 (80)	7.6 (25)	0.25	Yes	Flat bottom	Tungsten-carbide	Simple reverse
Hanford Site, Washington 47, small-diameter boreholes	Yes	Yes	Yes	≤345 (≤50,000)	7.6 to 66 (3 to 26)	Up to 1,725 (5,661)	30.5 (100)	Within specifications	Yes	Tri-cone and core	Tungsten-carbide and diamond	Direct

[a]Taken from Fenix & Scisson (1969).
[b]Taken from Fenix & Scisson (1983a, p. 18).
[c]Taken from Richardson (1984).
[d]Taken from Hunter (1983a).
[e]Taken from Horton (1967).
[f]Taken from Cobbs (1984).
[g]Taken from Wohlfeld (1983).

through the drill pipe. This method reduces the quantity of fluid required to lift drill cuttings to the surface, reduces fluid velocity in the hole, and aids stability of the rock wall.

An engineering assessment of large-diameter, blind-hole drilling has been made based on the data base provided from the small-diameter drilling activities in the reference repository location and vicinity. Despite the difficulty in extrapolating from small-diameter boreholes to large-diameter shafts, the high degree of success in drilling small-diameter boreholes on the Hanford Site is a positive indication that drillability, hydrologic conditions, and stability concerns can be managed in excavating exploratory and repository shafts.

Core disking has been encountered in core hole drilling in the reference repository location. This phenomenon has not presented major problems to the drilling activity, except for an occasional jamming of the core barrel. The high, anisotropic stress field may contribute to disking (see Subsection 5.1.3.2.3).

Deterioration of the boreholes on the Hanford Site has been observed, but has not resulted in the bridging or collapse of any of the boreholes. It is believed that the high, anisotropic horizontal stresses result in spalling. Once stress relief has occurred, the borehole walls stabilize, as observed in boreholes that frequently require reentry. As a precautionary measure, a drill bit of the borehole gauge is lowered into the borehole for cleaning prior to instrument installation. In past experience, the cleanout tools have passed to the bottom of the boreholes without obstruction. A small amount of material frequently is present in the bottom of the boreholes. This material is thought to be due primarily to long-term deterioration of the drilling fluid or mud that cakes on the borehole walls and eventually sloughs off and falls to the bottom of the unlined borehole.

In a large-diameter shaft, concern over joint spacing and high in situ stress that can generate spalling conditions can be mitigated by the presence of a high-density drilling fluid. Large-diameter shaft-drilling experience suggests that a drilling fluid pressure of 14 megapascals (2,000 pound-force per square inch) is exerted against the shaft wall. This pressure, coupled with the reduction in radial rock stress due to a small amount of joint loosening, is sufficient to reduce the slabbing and spalling, even though the in situ pressures are five times greater than drilling fluid pressure. However, spalling of large wedges or blocks of rock from the shaft wall could occur. These blocks of basalt may break off beneath, along side of, or above the down-hole tool assembly. In the event that rock instability is encountered, mitigating measures have been developed to remove the broken rock from the hole and to condition the hole prior to the resumption of normal drilling or lining operations. These measures address all reasonable scenarios that could be encountered during construction (Morrison-Knudsen Co., Inc., 1983a; Webster, 1984).

Fracture data indicate that typical block sizes expected to spall from the shaft wall are small even in the colonnades. The colonnade of the Cohassett flow has a mean fracture spacing of 13 plus or minus 4 fractures per meter (4 plus or minus 1 per foot) (Long and WCC, 1984, p. I-76). This implies a block size on the order of 10 centimeters (4 inches). The small block size results from columnar blocks that are subdivided by fractures. The irregular, wavy nature of basalt columns is well documented (Long, 1978, pp. 20 through 22; Long and Davidson, 1981, pp. 5-18 through 5-23). This irregular geometry results in a general interlocking of the rock mass, which reduces the likelihood that individual columns would slough from the wall. Conditions under which such sloughing might happen are apparently restricted to cases in which the arc of the shaft wall intersects columns in such a way that considerably less than half of a column remains in the shaft wall. Consequently, the size of fragments likely to slough off the wall is further reduced. Blocks of this size are expected to be handled by routine drilling techniques.

Drilling fluid losses are not expected to constrain shaft drilling. Losses of drilling fluid have been experienced during small-diameter borehole drilling on the Hanford Site. Most of the fluid losses have taken place during coring operations, which have high fluid pressures. Past drilling experience on the Hanford Site has allowed the evolution of drilling fluid programs to address and mitigate this potential problem. During shaft construction, circulation fluid levels would be monitored by measuring the volume of drilling fluid used. Some losses, such as evaporation of fluid from the mud pits, would be experienced. In the event that conditions indicate a loss of fluid, preventive measures would be employed (e.g., use of lost-circulation-control agents or the placement of a concrete plug) (Morrison-Knudsen Co., Inc., 1983b, 1984). These are common drilling-industry practices.

All confined aquifers at the reference repository location can be described as artesian. Hydraulic heads encountered do not rise above approximately 50 meters (165 feet) below ground surface in the reference repository location (see Section 3.3.2). Consequently, high-water-pressure effects can be adequately mitigated against by controlling the height and density of the column of drilling fluid in the hole. To offset the ground-water pressure and temporarily stabilize the hole wall, the drilling fluid is designed and prepared prior to penetrating an aquifer. The location of the aquifer and the pressure expected would be determined based on prior drilling experience. However, the drilling fluid level would be monitored carefully at incremental points to assist in implementing any modifications to the fluid design. As the overpressure of fluid from the shaft to the aquifer is established, a filter cake of the drilling fluid material form in the aquifer zone, thereby reducing or preventing water movement or perturbation to the drilling progress.

Shaft-drilling experiences at other sites help to establish that large-diameter drilling at the reference repository location is within reasonably available technology. Examples of experience related to large-diameter shaft drilling are shown on Table 6-20. Although shaft drilling at these sites does not exactly duplicate the geologic, hydrologic, or design considerations of the proposed shafts at the reference repository location, the accumulated knowledge suggests that reasonably available technology exists to address the expected conditions. Mitigating measures developed by the large-diameter shaft-drilling industry have resulted in rapid technical advancement.

Drilling parameters studied by the industry at the sites listed in Table 6-19 include rotary table revolutions per minute, rotary table torque, drilling rate, air pressure, fluid rate, fluid volume, hole alignment, and general bottom hole conditions relative to removing efficiently the rock cuttings and transporting them to the surface. Similar information would be collected and assessed for basalt during drilling of the exploratory shafts, and the information gained would be used to refine repository-drilling techniques.

The rig expected to be used for drilling the exploratory shafts, Geodril Rig No. 32, was used to drill a 3-meter- (10-foot-) diameter Tonopah shaft in Nevada. Subsequent to that operation, the rig had been used primarily in the petroleum industry for drilling of very deep holes. One borehole was a gas well that was drilled to a depth of approximately 9,570 meters (31,400 feet) (Loffland Brothers Company, 1974). Since the manufacture of the rig in 1968, it has been modified and upgraded. The rig is rated as one of four rigs in the free world capable of drilling the exploratory shafts at the reference repository location on the Hanford Site (Morrison-Knudsen Co., Inc., 1983a). Independent reports have been prepared to define shaft-drilling design and development needs (RKE/PB, 1984a; Fenix & Scisson, 1983a; Morrison-Knudsen Co., Inc., 1984). Equipment such as Geodril Rig No. 32 can be modified to be capable of drilling repository-size shafts to depths of approximately 1,220 meters (4,000 feet) at the reference repository location.

Using proven technology (defined as technology and components that have actually been successfully employed in the field), the largest diameter hole that can be drilled with confidence in a single pass to 1,220 meters (4,000 feet) at the reference repository location is approximately 4.6 meters (15 feet) (RKE/PB, 1984a). This limit is based on analyses using current maximum capacities and conditions as follows:

- Rig hoist capacity or rated hook load--8.9 meganewtons (2,000,000 pound-force).
- Rotary table peak operating torque--540 kilojoules (400,000 foot-pounds).
- Tungsten-carbide insert cutters (Fenix & Scisson, 1983b).
- Flat-bottom bit with approximately 20 cutters.
- A 34.0-centimeter (13.375-inch) outside diameter single-wall drill string.

Table 6-20. Comparison of relevant large-diameter shafts to the Basalt Waste Isolation Project proposed repository shafts

Location	Hole diameter, m (ft)	Depth, m (ft)	Rock type
Reference repository location, Washington[a]	4.57 (15)	1,036 (3,400)	Basalt
Nevada Test Site, Nevada[b]	0.91 to 2.79 (3 to 9.17)	335 to 1,280 (1,100 to 4,200)	Volcanic tuff-rhyolite-granite
Amchitka Island, Alaska	2.29 (7.5)	1,875 (6,150)	Breccia-basalt
Agnew, West Australia	4.27 (14)	750 (2,460)	Schist-metagabbro-gneiss
Summer Falls, Washington	1.98 (6.5)	18 to 24 (60 to 80)	Basalt
Tonopah, Nevada	3.05 (10)	1,448 (4,750)	Volcanic tuff-rhyolite
Crownpoint, New Mexico	1.83 and 3.05 (6 and 10)	667 and 684 (2,188 and 2,243)	Shale-sandstone

[a]Proposed shafts.

[b]Collectively refers to several large-diameter shafts drilled at the Nevada Test Site.

- Pumps and compressors as required.

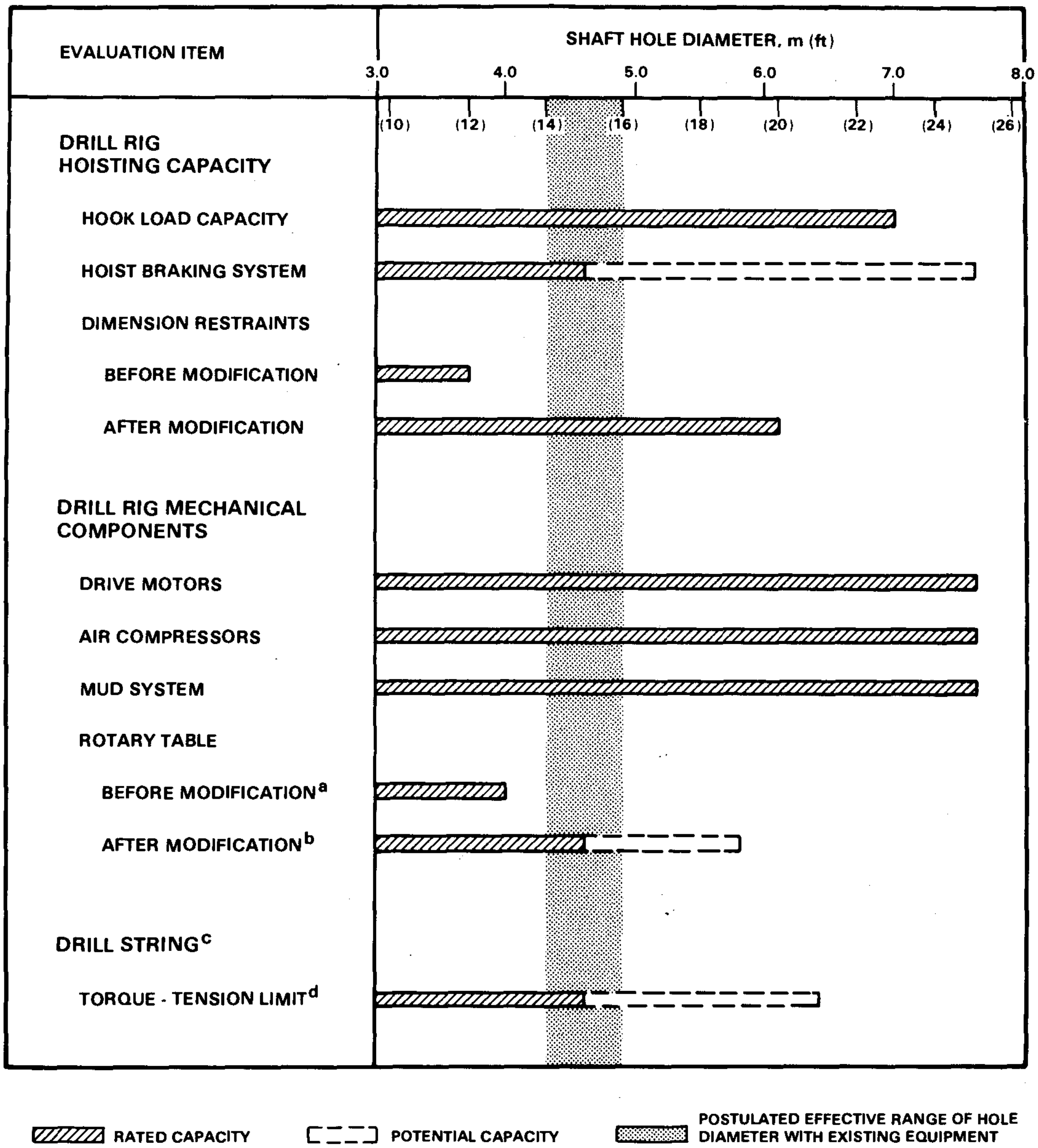
- Standard drilling fluid design.

Modifications to Geodril Rig No. 32 would be required to drill a 4.6-meter (15-foot) hole, which is the diameter expected to be required for repository operations (RKE/PB, 1984a). An evaluation of capabilities of Geodril Rig No. 32 is provided in Figure 6-9 (Morrison-Knudsen Co., Inc., 1984).

Experience from drilling the Agnew mine ventilation shaft in West Australia provided a recent representative hard-rock case history. This shaft was blind-hole drilled to a depth of 750 meters (2,460 feet) at a diameter of 4.3 meters (14 feet). Drilling was curtailed 280 meters (918 feet) short of its intended depth of 1,030 meters (3,378 feet) after experiencing structural problems with the mast and rotary support beams provided with the Hughes CSD-300 Series drill rig. This failure was not related to torque capacity, but resulted from excessive lateral vibration in the rig superstructure (Richardson, 1984). The rock mass excavated was metagabbro, schist, and gneiss, with compressive strength values that ranged from 200 to 400 megapascals (29,000 to over 58,000 pound-force per square inch). This range of rock strength compares with basalts in the reference repository location. For example, the Cohassett flow has a mean compressive strength of 290 megapascals (42,000 pound-force per square inch) and ranges from approximately 200 to 400 megapascals (29,000 to 58,000 pound-force per square inch) (Rockwell, 1983b). The average torque required to drill the metagabbro and schist exceeded 271 kilojoules (200,000 foot-pounds). The Hughes rig was capable of applying 690 kilojoules (500,000 foot-pounds) of peak torque capacity, considered adequate for addressing the hard-rock conditions encountered. The 328-day duration accounted for an average production rate of approximately 2.1 meters (7 feet) of advance per day. Some of the delays incurred resulted from inability to obtain or manufacture spare parts in the remote West Australian location.

With the Geodril Rig No. 32 rated hook load of 8.9 meganewtons (2 million pound-force) and allowing 25 percent for pull-out allowance, 0.44 meganewton (100,000 pound-force) for hook, blocks, and rope, and 1.8 meganewtons (400,000 pound-force) for the (buoyant) weight of the drill string, available capacity of the rig to lift the down-hole tools is approximately 4.4 meganewtons (1 million pound-force), of which only approximately 60 percent can be employed as load on the cutters. Based on cutting test data (Fenix & Scisson, 1983b) and this load, the ideal advance rate is approximately 7.3 meters per day (24 feet per day) for a 4.6-meter- (15-foot-) diameter shaft. Adjusting this rate for cutter wear, imperfect cleaning, and available drilling hours, a daily advance rate of approximately 2.4 meters (8 feet) per day is predicted. The required peak torque would be on the order of 407 kilojoules (300,000 foot-pounds) (RKE/PB, 1984a). Based on these analyses, the rig performance is limited primarily by the rig hoisting capacity.

7 0 1 6 8 1 2 8 8



[a] PRESENT ROTARY TABLE SIZED FOR THE EXISTING 279.4-cm- (110-in.-) DIA EXPLORATORY SHAFTS AND HAS UPPER WORKING LIMIT OF 217 kJ (160,000 ft-lbf).

[b] DRILLING OF SHAFT(S) LARGER IN DIAMETER THAN EXISTING EXPLORATORY SHAFTS WOULD REQUIRE INSTALLATION OF STRONGER ROTARY TABLE.

[c] A 34.0-cm- (13.375-in.-) DIA STRING.

[d] RECOMMENDED MAXIMUM TORQUE-TENSION LOADING OF EXISTING EXPLORATORY SHAFT DRILL PIPE 339 kJ (250,000 ft-lbf) IS THEORETICALLY REACHED AT APPROXIMATELY 1,220 m (4,000 ft) WITH A 4.6-m- (15-ft-) DIA EXTENDED, PERHAPS TO APPROXIMATELY 6.1 m (20 ft).

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Figure 6-9. Geodril Rig No. 32 large-diameter shaft evaluation (after Morrison-Knudsen Company, Inc., 1983a).

Agnew mine data indicate that dual-string, jet-assisted flushing, employing a 50.8-centimeter (20-inch) dual string, can adequately flush the cutting surface under a 4.3-meter (14-foot) flat bit. The flow rate for this system was estimated to be 156 liters per second (2,500 gallons per minute). It is expected that a single-string flushing system with a 34.0-centimeter (13.375-inch) string would provide adequate flushing for shafts of this diameter.

The Agnew mine had previously sunk an exploratory shaft to the same geologic horizon using drill-and-blast methods. This shaft excavation required nearly 3 years to complete and the project experienced difficulties resulting in the loss of 5 lives and 63 lost-time accidents. The blind-hole-drilled portion of the Agnew ventilation shaft resulted in no loss of life and only one lost-time accident (Richardson, 1984). The Agnew mine shaft experience not only substantiates the safety aspects of blind-hole drilling, but also provides information needed to refine designs of the rig superstructure to address vibration concerns when drilling through hard-rock formations. This experience demonstrates that shafts can be constructed in hard rock at acceptable penetration rates.

A functional repository shaft requires a liner to provide permanent ground support and also to avoid ground-water intrusion. The shaft liner would be designed to withstand the potential hydrostatic pressure that might be encountered with a load factor of 1.5 or greater. Alignment of the hole would be maintained during drilling to assure that the liner could be properly placed. The alignment of the hole is a function of the drilling operation and relies on proper tensioning of the drill string, rate of advance, and maintenance of the stabilizers to provide a balance between the revolutions per minute and the weight on the bit to assure proper stabilization. Such parameters are continually checked and analyzed against down-hole alignment surveys to assure straightness of the hole. Technology for placement of a liner has been demonstrated (Table 6-21). There are concerns, however, about the rate of installation of the liner (RKE/PB, 1984a). A repository-sized shaft would require a liner composed of high-strength alloy steel. Field welding would require lengthy controlled cool-down periods to avoid microfractures in the steel adjacent to the welds. During liner installation, the shaft wall is supported by the drilling fluid and is potentially subject to time-dependent deterioration. Future engineering studies may result in an alternate method(s) of joining the liner segments to reduce installation time required, thus minimizing the potential of hole deterioration.

After installation, the liner would be grouted into place through slotted grout line guides attached to the outer steel liner wall. A portland cement grout would be injected into the annulus between the liner and the rock wall to support the liner in the hole and to prevent water movement along the annulus (see Subsection 6.3.1.3.5). The gel strength, density, and viscosity contrasts between the grout and the drilling fluid would be adjusted to allow displacement of the drilling fluid by the grout. Inspection of the grout integrity and any secondary (chemical) grouting if needed would be provided through inspection port-holes preinstalled in the liner. Although the need for secondary grouting

Table 6-21. Case histories of steel and composite liners

Location	Diameter (ft)		Depth (ft)	Type of liner	Comments
	Drilled	Casing ID			
Amchitka, Alaska	7.5	4.5	6,150	Steel	--
Piceance Creek, Colorado	10.0	8.0	2,371	Steel	Drilled to 11.75 ft, for upper 195 ft
Crownpoint, New Mexico	10.0	7.1	2,190	Steel	Also second (smaller) shaft
Tonopah, Nevada	10.0	--	4,846	Steel	--
Amchitka, Alaska	10.0	--	4,550	Steel	--
Grants, New Mexico	16.5	14.0	784	Steel	Kerr-McGee mine
Beatrix, Holland	25.0	18.5	1,650	Composite	Outer shell: Welded channels Inner shell: Bolted channels
Saskatchewan, Canada	--	18.2	2,188	Composite	Inner steel: 4.6 cm (1.8 in.) Outer steel: 4.1 cm (1.6 in.) Core: 6.86 cm (27 in.)
North Yorkshire, England	--	18.0	3,110	Composite	Inner steel: 5.1 cm (2.0 in.) Outer steel: 4.1 cm (1.6 in.) Core: 7.62 cm (30 in.)
Huckelhoven Aachen, West Germany	14.7	10.2	1,312	Composite	Outer steel shell only: 1.0 to 2.5 cm (0.39 to 1 in.) Core: 3.00 cm (12 in.)

NOTE: After Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas, Inc. (RKE/PB, 1984a). Original data in feet; 1 foot = 0.31 meter. ID = inside diameter.

is not expected, provisions have been established in conformance with industry practice (Cobbs, 1981). A chemical sealant could provide an additional barrier to water movement at selected intervals. This material was successfully used at the Crownpoint shaft in Grants, New Mexico (Hunter, 1983a). The liner and grouting process would rely on available materials and technology.

Excavation of the subsurface facility

The drill-and-blast method is planned for excavation of the repository subsurface facility. This method has been in wide use for civil and mining projects and no technology development activities would be required. Field tests to optimize equipment selection and drilling patterns may be necessary during exploratory shaft construction.

During excavation of any underground facility below the water table, construction problems related to the inflow of ground water can develop. Techniques are developed to mitigate the expected ground-water conditions at the reference repository location; therefore, engineering measures beyond reasonably available technology will not be required.

Conditions at the reference repository location are potentially hazardous with regard to ground-water inflow, because of the proximity of water-bearing flow tops to the repository horizon. Preliminary scoping studies by Baker (1985) suggest that, under expected repository conditions, water inflow for an 8- by 10^6-square-meter (8.6- by 10^7-square-foot) repository area is expected to be low, on the order of 0.006 cubic meter per second (100 gallons per minute). (However, there is a large uncertainty associated with this ground-water inflow estimate.) For these analyses, the repository excavations were located near the center of the Cohassett flow interior. The actual inflow to the repository will depend on the number and hydraulic characteristics of the water-bearing features intersected during excavation and the application of remedial actions such as grouting. Ground-water inflow from atypical situations (e.g., encountering a high-permeability flow top or shear zone) sufficient to cause a safety hazard to underground workers is a concern at the reference repository location as in any underground operation.

Baker (1985) also made a preliminary estimate of ground-water inflow resulting from unexpectedly excavating into a flow top having a hydraulic conductivity of 10^{-7} meter per second (10^{-2} foot per second). The ground-water inflow to the drift was calculated to be approximately 0.006 cubic meter per second (100 gallons per minute). In a worst-case scenario of the drift penetrating a flow top having a hydraulic conductivity of 10^{-5} meter per second (10^{-0} foot per second), the ground-water inflow calculated was approximately 0.20 cubic meter per second (3,300 gallons per minute) after 1 minute. This inflow would decrease to approximately 0.12 cubic meter per second (1,800 gallons per minute) after 100 minutes.

These calculations are considered conservative, because the excavation would generally advance only about 2.5 meters (8 feet), whereas the calculations assumed an instantaneous penetration of 10 meters

(32.8 feet). Also, no mitigative measures were assumed to have been established, whereas preexcavation drilling and grouting are expected to be relied on to control inflows prior to occurrences such as those assumed in the calculation.

Baker (1985) also evaluated the ground-water inflow into a single borehole used to probe the ground-water conditions ahead of the mine face. Inflow estimates into the borehole were significantly lower than those calculated for the drift. For example, a borehole intersecting a 10-meter- (33-foot-) thick flow top would produce approximately 0.001 cubic meter per second (16 gallons per minute). For these calculations, a hydraulic conductivity of 10^{-7} meter per second (10^{-2} foot per day), storativity of 10^{-5}, and a hydraulic head of 900 meters (2,950 feet) were assumed. Although the above inflow estimates are preliminary, it is believed they represent a realistic conservative upper bound of water inflow.

Inadvertent penetration of a flow top is considered an unlikely event, because the Cohassett flow is sufficiently thick to provide adequate flexibility in locating the repository excavations at least 15 meters (49 feet) below the flow top.

The hydraulic conductivity of the vesicular zone is estimated to be higher than the dense interior and less than the flow tops (see Subsection 3.3.2.1). Excavation through or in the vesicular zone is not expected to produce abnormal ground-water inflow. The vesicles and vugs observed in the vesicular zone of the Cohassett flow are not interconnected, and jointing within the zone is generally consistent with the columnar portions of the flow.

Forward-probing holes would be drilled to assure the location of the excavation relative to the bounding flow tops. The vesicular zone, located between 21 and 23.5 meters (68 and 77 feet) below the Cohassett flow top, can be used as a marker horizon to locate the repository excavations relative to the flow top. These holes would be drilled prior to breakout from shaft stations and other openings as needed. These long, small-diameter boreholes may be needed to detect the presence of water, gas, or geologic anomalies. The final repository design would provide flexibility so that geologic anomalous zones encountered during probing could be investigated prior to proceeding with excavation. Pressure grouting methods could be used to pretreat these zones prior to excavation. Grouting is a common industrial technique used in underground construction to limit water inflow.

In addition to precautions taken to detect water-bearing zones, the repository design would provide for drainage to pumping stations and sumps at the bottom of each shaft to accommodate water inflows. During early construction, emergency pumps would be located in the shaft sump to provide the capability for removing ground water.

Although some ground-water inflow into the repository openings is expected, large ground-water inflows would be avoided or, if encountered, can be mitigated. Examples of underground projects built with the aid of drainage techniques are given by Jorge and Mouxaux (1978). Numerous examples of underground water occurrence, their effects, and applicable control measures are given in Cummins and Given (1973). Ample technology exists to grout such zones and alternately drain or draw down the water-bearing feature to assure the excavation would not be flooded.

In situ rock characteristics that may affect opening stability and require rock support beyond that which is commonly available must also be considered. A detailed discussion of the rock-support system requirements for underground openings is given in Subsection 6.3.3.2.4. To conservatively assess repository constraints to the support system, the waste-emplacement rooms are generally used as the typical design cross section for considering repository conditions. Construction of underground space for facilities in the shaft pillar is less restricted compared to emplacement rooms and entries. Equipment storage, shop facilities, offices, warehouses, sumps, and shaft loading pockets may require simpler support techniques. It has been determined that rock-support system requirements in emplacement rooms, entries, and ventilation drifts could be met with some combination of rock bolts and shotcrete. Such materials are commonly used for rock reinforcement throughout the world. Rock bolt patterns expected for the repository range from spot bolting of untensioned bolts (dowels) in fair rock conditions to patterned bolting of tensioned bolts with various bolting densities in extremely poor rock conditions. The requirements for shotcrete application vary from 2 to 3 centimeters (0.8 to 1.2 inches) and 8 to 16 centimeters (3 to 6 inches) of thickness. Shotcrete in thickness greater than 5 centimeters (2 inches) may include reinforcement with welded wire mesh. Various shotcrete mix designs, using welded wire fabric, fibers for reinforcement, microsilica for strength, and other additives to influence material characteristics are commercially available. Long-term performance of support system materials under repository conditions may require testing. Areas of testing that may be considered for site characterization include long-term rock bolt and rock interaction, rock bolt and grout performance, and shotcrete and rock bonding, which may lead to some development work. Development of such long-term rock-support systems is not considered beyond the means of reasonably available technology.

The potential for rock bursts during construction or the later thermal period (waste emplacement) must be considered in assessing the need for technology development. Rock bursts are generally defined as the release of stored strain energy in the form of a kinetic rock displacement. These are discussed in Subsection 6.3.3.2.10. Large rock bursts are generally associated with unjointed blocks of rock and high extraction ratios. The Cohassett flow interior is closely jointed (see Subsection 3.2.2.3). Slip and displacement along the joint system would tend to dissipate some of the stored strain energy. This is expected to minimize the potential rock bursts in basalt compared to those in more massive rock under similar stress conditions. Blake (1984) and Barton

(1986) have evaluated the potential for rock bursts at the reference repository location and concluded that only minor rock bursts or spalling at the time of excavation are expected. Blake (1984) notes that rock bursts are generally associated with sites having all or most of several common characteristics. These characteristics include depth, high in situ stress, massive, strong, brittle rock, high extraction ratio, extensive area of mined-out ground, wide spans resulting in a low stiffness loading system, geologic structural discontinuities, complex arrangement of geologic formations, narrow and tabular opening geometry, and maximum principal stress essentially perpendicular to the tabular dimension. Depth, high in situ stress, and a tabular opening geometry are the characteristics that are expected at the reference repository location. However, because of the absence of so many of the other characteristics that contribute to rock bursts, particularly a high extraction ratio and geologic complexities, there will be a low potential for rock bursts during construction of a repository in the Cohassett flow. Blake (1984) states that there is a moderate potential for small-scale phenomena (e.g., spitting and popping rock during excavation). Such phenomena are not a serious operational problem and can be safely and effectively dealt with by using available rock reinforcement methods. Thus, no new technology is required for successful construction under the expected conditions. The proposed rock-support system (rock bolts and shotcrete) has been used to control similar conditions in other rock types at other construction projects (e.g., Saito et al., 1983; Myrvang and Grimstad, 1983).

A microseismic system would be used to determine zones of relief or potential stress buildup. Support to mitigate against rock bursts generally consists of bolting the area that has a potential for rock burst and of shotcreting, using rapid setting, high-strength-mix designs. Alternately, areas expected to exhibit high stress concentration may be destressed by pretreatment, using drilling and small-charge blasting methods.

The presence of toxic or flammable gas in an underground facility during construction or operation could result in potentially hazardous health and safety conditions. However, the conditions expected at the reference repository location are not adverse when compared to many operating coal mines. Ground-water samples obtained from the Cohassett flow are partially saturated (approximately 50 percent) with methane gas (Rockwell, 1983c). Methane has been produced commercially from wells located near anticlines (e.g., the Rattlesnake Hills gas field; see Fig. 3-37) in the vicinity of the reference repository location (see Subsection 6.3.1.8). Exploration drilling in the Saddle Mountains 26 kilometers (16 miles) north of the reference repository location has encountered methane gas at depths of approximately 4,570 meters (15,000 feet) in sedimentary rock below the Columbia River Basalt Group. Methane, however, is not indigenous to basaltic rock. Stratigraphic entrapment of methane gas is not expected in the broad synclinal region of the reference repository location. Significant quantities of methane are not expected to enter the excavated opening, since this gas is mainly introduced by ground-water inflow. As described previously, methane and ground-water quantities are expected to be monitored to limit methane concentrations using standard industry practices.

Methane accumulation in the repository would be prevented by dilution with ventilation air and by limiting water inflow. Figure 6-10 shows the explosion hazard curve for methane and the design limits used to calculate the ventilation air-dilution requirements. The preliminary methane-inflow rate for the entire repository, assuming all of the available methane in the ground water is liberated, is estimated to be 0.38 cubic meter (13.4 cubic feet) per minute (Rockwell, 1985). This amount of methane requires 151 cubic meters (5,300 cubic feet) per minute of fresh air to maintain a concentration of less than 0.25 percent (the upper limit value established by the Mine Safety and Health Administration (1983)). The ventilation airflow rate for the repository is 28,000 cubic meters (1 million cubic feet) per minute with over 8,500 cubic meters (approximately 300,000 cubic feet) per minute provided in the main entry drifts, with a minimum velocity requirement of 0.3 meter per second (60 feet per minute) in a development drift (RKE/PB, 1984b). This provides 191 times more fresh air available than needed to dilute the methane to less than 0.25 percent. Even during unexpected high water-inflow rates of 0.2 cubic meter per second (3,400 gallons per minute) into a development heading, the ventilation air provides sufficient fresh air to dilute the methane to less than 0.25 percent. Figure 6-11 shows the concentrations of methane in the return airways of gassy and nongassy mines (Thimons et al., 1985). The repository gas inflow is projected to be well below 0.25 percent (2,500 parts per million). Methane inflow to the repository is based on a water inflow of 0.2 cubic meter per second (3,400 gallons per minute) total release of available methane (determined from largest occurrence observed (700 milligrams per liter (700 parts per million)) and all inflow into a single development heading. The exploratory shaft program would provide data for design analyses on measured methane concentrations defined by observation of the test facility return air.

The following specific precautions would be taken during the design, construction, and operation of the repository to detect and mitigate the presence of methane gas.

- During repository construction, methane monitoring and forward-probing boreholes would be provided to assure that the presence of methane gas would be detected.

- The ventilation system for the repository would be designed to provide for the excess flow of ventilation air required to dilute methane gas encountered and to exhaust this gas from the underground facility (RKE/PB, 1984b).

The Cohassett flow temperature (51°C (124°F)) is a potential health hazard to personnel working underground. Elevated rock temperatures are frequently encountered in underground mining operations. A few examples are given in Table 6-22 and additional data on geothermal gradients in worldwide mining districts are given by Hartman et al. (1982). Underground operations cited in Table 6-22 use refrigeration-assisted ventilation air to create a suitable working environment. The repository ventilation system would be designed to provide a continuous moderate workload environment for individuals according to standards adopted by the American Conference of Government Industrial Hygienists (ACGIH, 1982).

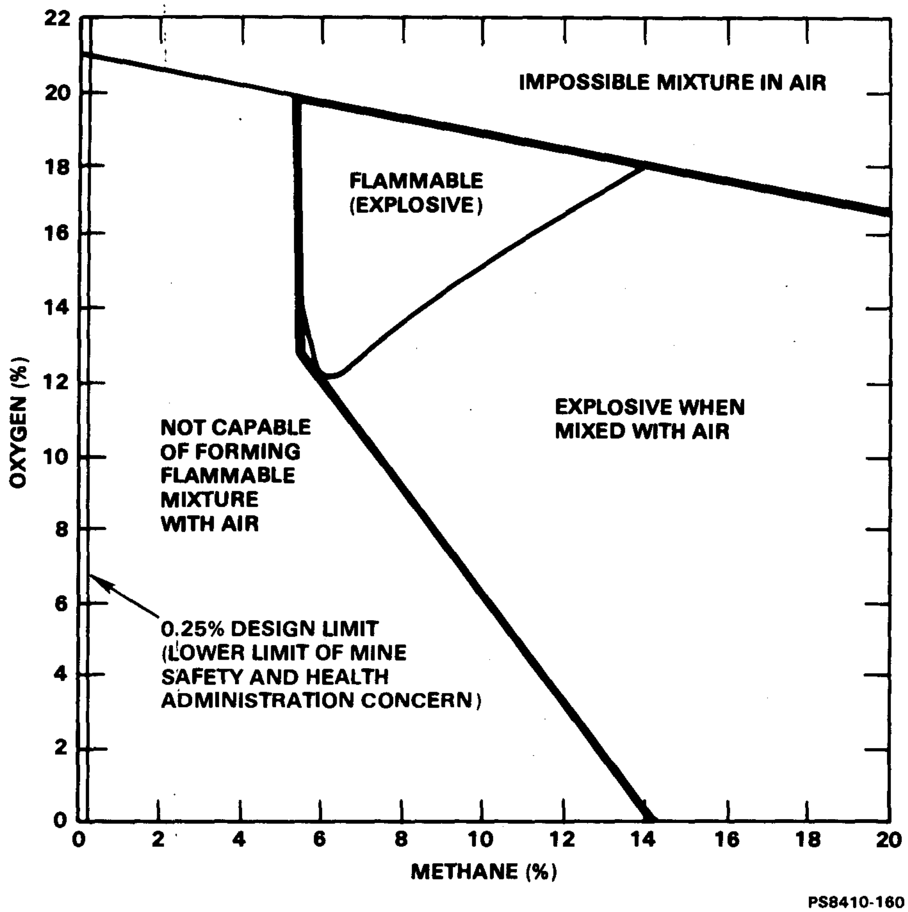


Figure 6-10. Explosibility curve for methane (after Hartman et al., 1982).

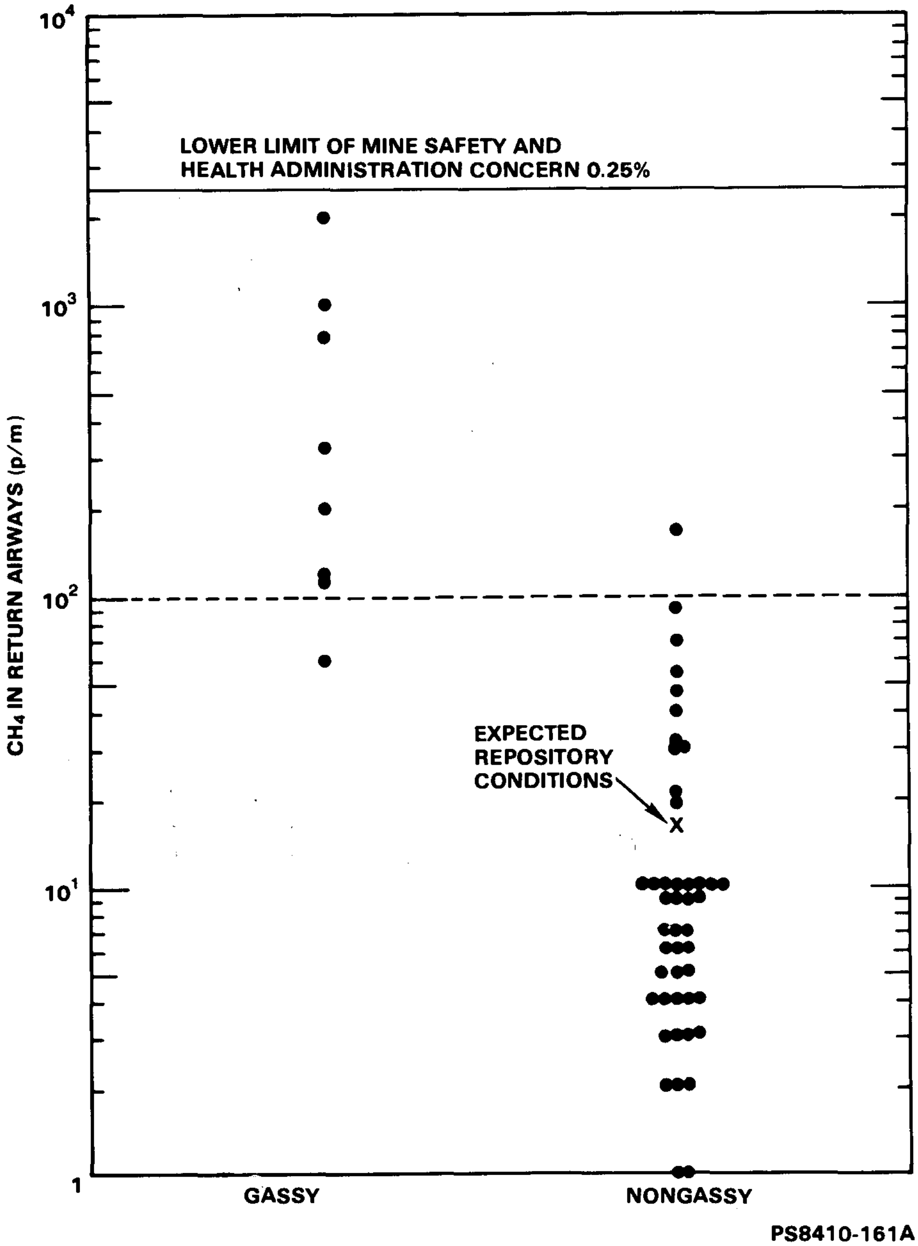


Figure 6-11. Methane concentrations found in air returns of gassy and nongassy mines (after Thimons et al., 1985).

Table 6-22. Underground operations using refrigerated-assisted ventilation air for cooling

Operation and (or) location	Virgin rock temperature °C (°F)	Source
Magma Copper Company, Arizona	53 to 60 (127 to 140)	Peele (1947), pp. 14-56 and 14-63
Morro Velho, Brazil	51 (123)	Peele (1947), pp. 14-59
Turf Shaft, South Africa	38 (101)	Peele (1947), pp. 14-60
Zeche Radbod, Germany	44 (111)	Peele (1947), pp. 14-61
Kolar Goldfield, India	51 (123)	Peele (1947), pp. 14-61
Butte, Montana	60 (140)	Hartman et al. (1982), p. 566

The repository ventilation system would provide airflow and mechanical refrigeration (e.g., local coolers or water chillers) to reduce the air temperature to acceptable levels. Heat transfer from the rock wall to the ventilation system depends on the temperature difference between the rock wall surface and the ventilation air. Initially, when the opening is excavated, heat flow into the mine is at a high rate. Subsequently, the layer of rock adjacent to the opening cools to essentially the same temperature as air in the opening, retarding heat transfer. The rate of heat flow from deep within the rock to the opening depends on the thermal properties of the rock. Temperature gradients develop in the rock wall. The longer the period of rock cooling, the less the temperature gradient. Thus, the newly exposed opening has higher temperature gradients than older or previously developed openings. If ventilation airflow were to stop, the air temperature would remain cool for a longer period of time in openings that have been ventilated longer.

An additional safety concern is the ground-water temperature of 51°C (124°F) at the depth of the Cohassett flow. Sudden inrushes of water at this temperature could cause body burns (Hartman et al., 1982, p. 569). Water inrushes or inundation would be detected by drilling forward-probing boreholes. Engineering measures beyond reasonably available technology for construction of shafts and underground facilities are not expected.

Personnel health would be monitored on a routine basis. Records of incidents related to the health of personnel would be kept. Rock temperatures and gradients would be measured and documented on a continuing basis. The efficiency of labor under moderate workloads in the repository environment would be determined by methods proposed by the American Conference of Government Industrial Hygienists (ACGIH, 1982). Thus, while heat stress is of concern relative to the health and safety of personnel, this occurrence can be mitigated by application of safety provisions proven acceptable in the mining industry.

6.3.3.2.7 Potentially adverse condition

"(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure."

Maintenance of underground openings is generally required as the result of time-dependent deformation of the rock mass (creep), excavation- or thermal-induced stress changes, or changes in ground-water conditions. Near-surface openings in basalt and at-depth openings in similar hard rock suggest that excessive maintenance would not be required. Maintenance may include rebolting or reapplication of shotcrete in areas where deterioration of the support system is detected. Stress increases from the heat-generating waste would be controlled by selection of the waste-emplacement density so that excessive stress-induced maintenance is not expected. Local grouting and (or) drainage would control ground-water induced effects. Therefore, it is expected that this potentially adverse condition is not present at the reference repository location.

Observational and deterministic approaches can be used to evaluate maintenance requirements. The observational approach assumes that experience from observation of existing underground structures could provide guidelines for the design in question. The deterministic approach assumes that a design is created and based on an understanding of the cause and effects of the controlling factors, and that these factors can be quantified. As with many aspects of repository design, neither approach by itself is entirely satisfactory. The observational approach lacks comparable case histories; whereas the deterministic approach does not consider all mechanisms of the rock mass response nor the quantified interaction between the rock mass and rock-support-reinforcement.

Some aspects of this potentially adverse condition could be quantified by observation and comparison with maintenance problems encountered at other locations. For example, case history studies in basalt (not at depth) and other hard rock sites at comparable depths suggest that support systems could be installed that would require minimum maintenance during construction and pre-waste-emplacement. Snoqualmie Falls hydroelectric project near Seattle, Washington, includes turbine chambers, head and tailrace tunnels, and railroad tunnels that were excavated in basalt in the early 1900's and require minimal maintenance. Some of these excavations have no artificial rock support. Similarly, high-use accessways in many deep underground mines with higher in situ stresses than for the proposed repository in basalt require minimal maintenance. These types of openings routinely require rock-support system maintenance, generally on an as-needed basis.

The rock characteristics, depth, and stress conditions suggest that a combination of rock bolts and shotcrete would be adequate (see Subsection 6.3.3.2.6) to provide rock support in the Cohassett flow interior. Barton (1986) identifies the potential for slabbing or minor rock bursts in the colonnade during construction, but indicates that rock bolts and shotcrete are sufficient to control such local events (Saito et al., 1983; Myrvang and Grimstad, 1983). Blake (1984) also notes that the Cohassett flow has a moderate potential for spitting and popping of the rock mass that may present a nuisance to tunneling. However, Blake indicates that there is a low potential for rock bursts during repository construction, because of the absence of many characteristics that contribute to the occurrence of bursts, particularly high extraction ratio and geologic complexities (see Subsection 6.3.3.2.6).

The methods for selection of the rock-support system discussed in Subsection 6.3.3.2.4 considered maintenance requirements. In the rock quality system, the excavation-support ratio is selected to reflect user safety requirements (Barton et al., 1974). The excavation-support ratio reflects construction experience, in that the degree of safety and support demanded by an excavation is determined by the purpose of the opening and the presence of machinery and personnel. A low-value excavation-support ratio is used when roof falls cannot be tolerated and when a minimum of long-term maintenance is required. For example, an excavation-support ratio of 1.0 is used for power stations, major roads, railway tunnels, civil defense chambers, portals, and intersections. For comparison, an excavation-support ratio of 3 to 5 can be used for temporary conventional mine openings. In selecting the suggested rock-support systems for a repository in the Cohassett flow, Barton (1986, p. 78) used an excavation-support ratio of 1.0 for the main entries and intersections and 1.3 for the emplacement rooms. This illustrates that the rock-support systems recommended for the repository are expected to require a minimum of maintenance.

The empirical methods are of limited use in projecting underground maintenance requirements during the retrievable storage phase, because of a lack of experience where thermal-induced stresses are involved. However, the Cohassett flow interior is not the type of rock commonly associated with long-term opening stability problems as illustrated in shales, evaporites (salt), and other rocks with low rock mass qualities (as rated by the Barton et al. (1974) rock quality system or Bieniawski's (1973) geomechanics rock mass rating system). Basalt is not expected to degrade thermally nor be influenced by humidity or moisture variations (as can be the case for shale roofs in coal mines where long-term maintenance is often a problem). Full-scale testing at the exploratory shaft facility is expected to provide an at-depth demonstration of the heating effect on the rock mass stability at the canister scale. Excavation in areas of poor rock quality within the flow interior may require more maintenance than the majority of the excavations. These local areas could include vesicular zones or areas of high fracture frequency or abundant clay infilling. Such areas may be excluded from waste emplacement if opening stability problems were projected.

Without data from the exploratory shaft program, the deterministic method of analysis must start from simplified assumptions concerning the mechanical and thermomechanical responses of the rock mass. However, the results of this analysis are conservative and are consistent with the understanding of the material properties. The nonlinear and non-elastic response of the rock mass is attributed to blast-induced damage and stress-induced slippage along preexisting joints in the basalt. The rock-support system assures that the rock blocks around the opening stay in place; the support system is not intended to assure that all the rock is maintained in an elastic condition. Consequently, there is not a one-to-one correspondence between thermoelastic stresses (or stress concentrations around the opening), rock-support requirements, and maintenance requirements. If stress relief did not occur by joint slippage in the vicinity of the opening, the potential for and severity of rock bursts with associated rock-support maintenance requirements could be significantly higher.

Estimation of maintenance requirements for underground openings may require consideration of rock mass creep behavior. Even if the stress environment were static, there may be delayed opening instabilities due to the gradual movement of the rock mass. The creep behavior of the rock mass in the repository environment is difficult to quantify, because intact basalt behaves as a brittle material. Therefore, basalt is expected to show little tendency to creep (Singh, 1981, p. 112). A potential for time-dependent joint movement exists due to the smectite clay present within the columnar joint clay infilling. The clay is indurated and produces filled joints generally less than 0.1 centimeter (0.04 inch) thick. Many joint surfaces are partially coated infill material, while other surfaces have basalt to basalt contact. Laboratory shear strength tests (Mitchell, 1984) on natural joints indicate that basalt to basalt contacts control the shear strength of the joints not the infill material. This factor, combined with the irregular nature of the joint surfaces and their lack of lateral continuity, produces an interlocking structure that is not expected to creep.

Additional uncertainty in evaluating rock mass creep is introduced when rock temperatures increase following waste emplacement. The increase in temperature would produce higher stresses around the subsurface openings and reduce the rock mass strength. In addition, the creep rate is generally thermally activated. Therefore, even under static stress conditions, the creep rate would increase at higher temperatures. Such a condition would tend to increase the possibility of rock mass creep around the subsurface openings. The creep rate in basalt for expected temperature and stress changes is not projected to be excessive and should not require increased maintenance.

Ground-water conditions could potentially cause some maintenance problems associated with corrosion of rock bolts, deterioration or exfoliation of shotcrete, or erosion in areas of ground-water inflow. Localized grouting and (or) drainage systems would be undertaken during construction to minimize potential ground-water inflow and the long-term effect on the expected rock-support system. Some regrouting or support system maintenance could be required during repository operation and closure.

6.3.3.2.8 Potentially adverse condition

"(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation."

The basalt at the reference repository location is a physically and chemically stable rock that will be little affected by repository conditions. Evidence indicates that this potentially adverse condition is not present at the reference repository location.

Approximately 90 percent of the potential host rock consists of plagioclase, pyroxene, mesostasis glass, and iron-titanium oxides, which are anhydrous minerals (with the exception of some mesostasis that can contain minor amounts of water). The rock is fractured; any thermal-induced fracturing will be minor (Mitchell, 1986), and will not create a safety hazard. The secondary minerals, predominantly clays, form thin coatings along fractures, and are present in the basalt matrix. Laboratory studies up to 500°C (932°F) show only a minor decrease in strength with no decrease in strength with temperatures up to the expected maximum repository temperature of 200°C (392°F). Shrinkage of infill materials, which constitute less than approximately 0.3 percent (Long and WCC, 1984, p. I-26) of the total basalt volume, is not expected to decrease the joint strengths.

The stability of underground openings in the Cohassett flow interior and the response of the basalt to excavation and thermal effects have been evaluated (Barton, 1986; Voss, 1984; RKE/PB, 1984c; Mitchell, 1984). These studies included near-field mechanical and thermomechanical finite-element code calculations, rock-matrix property evaluation, and rock mass classification. They considered the physical, thermal, and mechanical properties specific to the Cohassett flow, the existence of cooling joints, and the in situ stress field measured by hydraulic fracturing tests. The results indicate (1) the mined openings are expected to remain stable through repository closure and (2) the effects of thermal-induced fracturing are very localized and limited to the immediate vicinity of the waste-emplacement holes and the periphery of the drifts.

Preliminary estimates predict a potential for rock-matrix fracturing in the immediate vicinity of the waste-emplacement borehole, but this fracturing should extend no more than 1.3 centimeters (0.5 inch) into the rock. The potential for borehole spalling during construction is minimized by orienting the emplacement boreholes perpendicular to the least horizontal stress. No structural degradation has been observed in two full-scale heater tests conducted in basalt at the Near-Surface Test Facility, even though the basalt was heated to 600°C (1,112°F). Kim and McCabe (1984, p. 1132) indicate that some new crack formation and joint opening occurred during full-scale heater tests, but there was no spalling or decrepitation. Detailed studies by Kasza (1986) did not identify any new fractures, but Kasza concluded that some fractures may have been enhanced. Until in situ data can be obtained, uncertainty exists about waste container retrieval, owing to the influence of fracturing of the rock mass around the waste container and on the stress field. Local fracturing is expected to relieve the stress buildup around the emplacement borehole. The effects of localized sloughing of the borehole walls would be minimized and waste retrieval enhanced by using a rigid shell lining in the waste-emplacement borehole.

Thermal-induced fracturing, joint slip, and (or) joint opening around the emplacement rooms is expected to be limited to within the damaged rock zone developed during construction. Stress changes and the dynamic loads imposed during excavation are expected to produce a damaged rock zone around the emplacement room on the order of 1 to 2 meters (3.3 to 6.6 feet) thick. This zone will be supported by rock bolts and shotcrete, as necessary. In examining the thermomechanical response of the rock in the near field, calculations (RKE/PB, 1984c; Mitchell, 1986) were made with closed-form solutions for circular holes (emplacement boreholes) and finite-element thermomechanical computer codes for analysis of stress and displacement around the emplacement room. Rock mass strength estimates were based on laboratory test data for intact basalt. These valves were reduced to account for jointing in the basalt flow in the manner demonstrated for granulated marble by Rosengren and Jaeger (1968). For a repository in the Cohassett flow, the analysis predicted that thermal-induced fracturing in the crown of the emplacement room would be limited to 21 centimeters (8.3 inches) and fracturing around the emplacement hole would be limited to 1.3 centimeters (0.5 inch). The thermal-induced fractures are expected to be contained within the damaged rock zone.

No minerals present in significant quantities (greater than a few percent) in the repository horizon are susceptible to thermal-induced dehydration, hydration, or radiation-related phenomena. Long and Woodward-Clyde Consultants (1984, p. I-111) summarize the distribution of minerals in the basalts at the reference repository location, and state that more than 90 percent of the proposed repository host rock is plagioclase, pyroxene, iron-titanium oxide, and other polycrystalline inclusions set in a glassy mesostasis. Alteration minerals are present in fractures, vesicles, and vugs and in the basalt matrix. High-temperature tests have shown no significant decrease in strength with temperature. Elevated temperature tests by Miller and Bishop (1979), Miller (1979a, 1979b), Foundation Sciences Incorporated (FSI, 1980a, 1981a, 1981b), and post-test characterization core-strength tests from the full-scale heater tests in the Pomona flow (FSI, 1980b, 1980c; Mitchell, 1984) show no significant strength change with temperatures up to 200°C (392°F) and only a 20-percent reduction in strength to 500°C (932°F). The maximum expected temperature adjacent to the container is 200°C (392°F). Therefore, even though some form of dehydration of alteration minerals may be possible, there appears to be no impact on strength of the basalt and, hence, no impact on safety during repository operation.

Safety hazards resulting from thermal-induced fracturing, hydration or dehydration of minerals, or other chemical or radiation-related phenomena are not expected during repository operation (preclosure). This determination is based on the rock-support system design, which is expected to provide a system sufficient to minimize maintenance and safety hazards typically associated with underground construction. Retrieval of containers is expected to be possible in lined boreholes.

Gamma radiation on rock immediately surrounding the waste will produce excitation and ionization of stoms in the rock and a small amount of atomic displacement (Spinks and Woods, 1976, p. 443). Based on the expected radiation dose, the percentage of atoms affected will be minute and no physical or chemical properties of the rock will be significantly altered by radiation.

6.3.3.2.9 Potentially adverse condition

"(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems."

Brine pockets and active dissolution fronts do not exist in a basalt medium (see Subsection 6.3.1.6). However, stratigraphic and structural features that could compromise the safety of repository personnel due to water inflow or construction problems have been identified in boreholes or outcrops in and around the reference repository location. Therefore, it is assumed that this potentially adverse condition is present at the reference repository location.

Stratigraphic or structural features known to occur in basalt flows (see Subsection 3.3.2.1) must be evaluated with respect to their potential effect on the safety of repository personnel. Examples of stratigraphic and structural features include the following:

- Flow-top breccia.
- Pillow palagonite zones.
- Spiracles.
- Faults or shear zones.
- Horizontal platy fracture zones.
- Columnar fans.

The likelihood and potential impact of each of these features is discussed in the following subsections.

Flow-top breccia

The Cohassett flow top ranges in thickness, as discussed in Subsection 3.2.2.3 and illustrated in Figures 3-13 and 3-14. These ranges indicate that flow top is not likely to be encountered during excavation of repository panel areas. Flow-top breccia amounts to approximately 50 percent of the Cohassett flow top. Based on Cohassett flow outcrop observations over distances of up to 3.2 kilometers (2.0 miles), the thickness of the flow top and, thus the flow-top breccia, varies no more than 10 meters (33 feet) over distances of 100 meters (328 feet). Based on these observations and flow thickness determined from boreholes in and around the reference repository location, it is judged unlikely that variations in flow-top breccia more extensive than those observed in outcrop will be encountered within the projected interior of the Cohassett flow.

Unintentional penetration of flow tops by drifts may require rock-support and (or) water-control measures over and above those used in the dense interior (see Subsections 6.3.3.2.4 and 6.3.3.2.6). Ground-water inflow, a potential safety hazard, is discussed in Subsection 6.3.3.2.6. Additional ground-water inflow-control measures could be expected, since most flow tops in the Grande Ronde Basalt have hydraulic conductivities between 10^{-5} and 10^{-9} meter per second (10^{0} and 10^{-4} foot per day) (see Subsection 3.3.2.1.2); whereas, reported hydraulic conductivities of basalt flow interiors are less than 10^{-10} meter per second (10^{-5} foot per day) (see Subsection 3.3.2.1.1). Baker (1985) has suggested that under normal operating conditions with repository excavation near the center of the Cohassett flow, ground-water inflows may be minimal. Nevertheless, penetration of the Cohassett flow top could produce inflows of up to 0.2 cubic meter per second (3,400 gallons per minute) (Baker, 1985). There is a large uncertainty associated with this ground-water inflow estimate. Such occurrences are considered unlikely and would be avoided during construction by monitoring the distance between the flow top and the excavation.

The conductivity of the vesicular zone in the Cohassett flow is indicated to be generally higher than for the dense interior and lower for a flow top. Penetration of the vesicular zone during excavation is not expected to produce high ground-water inflows (see Subsection 3.3.2.1.1.)

Pillow palagonite zones

Pillow palagonite zones and columnar fans have not been encountered in boreholes in the Cohassett flow within the reference repository location, nor have they been encountered in Grande Ronde Basalt penetrated by boreholes within the Pasco Basin (Long and WCC, 1984, p. I-135). No such zones have been observed in over 3.2 kilometers (2 miles) of Cohassett flow exposure. Pillow zones have been identified in the base of the

McCoy Canyon flow along the Columbia River north of the Pasco Basin. The pillow zone thickness increases in this area to as much as one-half the total flow thickness (Long and Davidson, 1981, pp. 5-1 through 5-55). The significance of pillow zones is that such zones are likely to be more permeable than either dense interiors or nonbrecciated flow tops and may produce high water inflows.

If a similar pillow zone were present in any of the Grande Ronde Basalt flows in the reference repository location, they would probably have been encountered by existing boreholes. It is, therefore, concluded that the likelihood of significant pillow zones occurring in the Cohassett flow is extremely low.

In the unlikely event that a pillow zone were encountered during repository development, water inflow and opening stability impacts are expected to be similar to those when encountering flow-top breccia. As for flow-top breccia, safety of repository personnel would be enhanced by an exploratory drilling program conducted prior to excavation.

Spiracles

Spiracles are openings or brecciated zones formed by steam explosions occurring when molten lava encounters a small stream or pond (see Fig. 3-35). These features typically extend less than 2 meters (6 feet) into the flow interior from the base and, thus, would not likely be encountered by the repository openings. In outcrops of the Cohassett flow, spiracles are rare; only three were observed over 3.2 kilometers (2 miles).

If an unusually large spiracle were to extend into the part of the flow used for repository openings, opening stability and water-inflow impacts are expected to be similar to those when encountering flow-top breccia. The probability of intersecting spiracles or other localized primary discontinuities determined during site characterization would be used as a basis for design of the exploratory drilling program to detect such features prior to excavating the repository openings.

Faults or shear zones

Small-scale faults and shear zones associated with deformation of the Cold Creek syncline are infrequently encountered in core holes within the reference repository location (see Subsection 3.2.3.3.3). These features typically are nearly vertical, less than 10 centimeters (4 inches) wide, and filled with tectonic breccia and secondary minerals. More extensive zones or tectonic breccia in the reference repository location are only known from two zones in borehole RRL-6 (see Fig. 6-3) and, therefore, other such zones in the vicinity are assumed present. The breccia from borehole RRL-6 are each approximately 1 meter (3 feet) in apparent thickness and are filled with tectonic breccia and secondary minerals.

Since small-scale faults and shear zones are nearly vertical and can intersect the flow top and bottom, these tectonic features could result in water inflow to a repository. An exploratory drilling program could be used to detect these features prior to excavation.

Horizontal platy fracture zones

Platy fracture zones are undulating, subhorizontal zones of increased fracturing that have been observed in outcrops of the Cohassett flow and other Columbia River basalt flows (Long, 1978, p. 28; see Fig. 3-35). Similar zones have not been identified in exploratory boreholes in the Cold Creek syncline. Such features may be difficult to identify in boreholes and, consequently, it must be assumed that platy fracture zones will be encountered during repository development. Such features may require increased rock support to maintain safety of repository personnel.

Columnar fans

Columnar fans or areas where columnar joints exhibit a radiating geometry have been observed in outcrops of the Cohassett flow. The limited volume sampled in cored boreholes does not permit detection of fans in single boreholes. However, it seems likely that fanning does occur in the Cohassett flow in the reference repository location. The effect of columnar fans on opening stability is not known. Areas of structurally controlled, stress-induced opening instabilities may develop in areas where well-developed fans have formed, potentially requiring additional rock support. The results of in situ observations during site characterization would assist in determining rock-support requirements when excavating within columnar fans.

In summary, in assessing the rock-support requirements, the empirical methods of Barton et al. (1974) and Bieniawski (1973, 1976, 1979) were applied to a range of expected rock conditions that encompasses most of the expected geologic structural features. Flow tops would be avoided by means of exploratory drilling in advance of excavation, and major faults are not expected. A range of rock characteristics can be expected, as the frequency of jointing and the occurrence of joint infill materials vary with location and position in Cohassett flow interior. Barton (1986) estimated that 4 percent of the drifts would require additional rock support above the base case. Until observations of the actual conditions at depth in the Cohassett flow have been completed, the effect of structural geologic features on construction cannot be fully evaluated. It is expected that available engineering measures would mitigate this potentially adverse condition.

If stratigraphic or structural features were encountered that may compromise the safety of personnel, a laterally flexible repository layout concept would be maintained such that the repository waste panels could be extended or relocated to a more geologically favorable area. As previously described, exploratory drifts, geophysical methods, horizontal and vertical exploratory boreholes, and geologic observations would be used to identify areas with unfavorable geologic features.

6.3.3.2.10 Disqualifying condition

"The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology."

Geomechanical data from laboratory, field, and in situ testing and from case history studies of similar underground construction projects suggest that the effects of potentially hazardous conditions on the construction, operation, and closure of a repository at the reference repository location are not expected to cause significant risk to the health and safety of personnel. This takes into account mitigating measures that use ". . . reasonably available technology." Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

A preliminary assessment of excavated opening stability has been performed utilizing numerical techniques and empirical methods (see Subsection 6.3.3.2.4). Using measured rock strength and in situ stresses, numerical analyses were performed to determine repository opening shapes and spacings that result in acceptable rock stresses. It is difficult, however, to determine the degree of excavation support or rock reinforcement required from these numerical analyses. Therefore, empirical methods for excavation support determination were used (Barton et al., 1974; Bieniawski, 1973, 1979). These methods (developed from previous field experience), widely used in the underground construction industry, relate various parameters associated with rock quality to the degree of required opening stability. The results of the empirical assessments indicate that the rock mass would require some form of artificial support. The degree of support would vary with location, shape, and function of each opening, but all proposed openings could be excavated without causing significant risk to the health and safety of personnel. The recommended rock-support methods depend on the empirical method used and the intraflow structures encountered. The Bieniawski and Barton methods indicate that either bolting or shotcrete or a combination of both would be required (see Subsection 6.3.3.2.4). Although these empirical methods were not developed to predict the stability of heated openings, Barton (1986) applied the empirical techniques to accommodate additional thermoelastic-induced stresses and found no significant change in rock-support requirements.

The potential for rock bursts represents a personnel safety concern. Rock bursts can result from localized high-stress conditions and cause sections of the roof and walls of the opening to be ejected dynamically. Case history studies and analyses (Blake, 1984; Barton, 1986) suggest that severe rock bursts would generally not occur under expected repository conditions in the Cohassett flow. Case history studies (Table 6-23) and the empirical method of Barton et al. (1974) suggest that a repository in the Cohassett flow would be classified in the mild rock burst category. In the event that mild rock bursts are experienced during excavation of

Table 6-23. Rock burst case history comparison with expected repository conditions

Properties	Elliott Lake, Ontario, Canada	Kalem Gold Mine, India	East Rand Mines, South Africa	Star Mine, Idaho	Reference repository location, Hanford Site, Washington (expected conditions)
Depth, m (ft)	1,050 (3,440)	3,300 (10,830)	2,780 (9,120)	2,340 (7,680)	1,000 (3,280)
Compressive strength, MPa (lbf/in^2)	133 (19,300)	250 (36,300)	237 to 288 (34,400 to 41,800)	140 to 180 (20,300 to 26,100)	290 (42,100)
In situ stress, MPA (lbf/in^2)	60 (8,700)	105 (15,200)	-- --	80 (11,600)	60 (8,700)
Percent extraction ratio	80	100	85	100	20
Strength to in situ stress	2.2	2.4	--	1.7	4.8
Rock burst magnitude (Richter earthquake scale)	2.0 to 3.0	4.0	2.7	1.0 to 2.6	--
Amount of affected rock	Extensive bursting	--	Extensive damage in stope	550 t (500 tons)	--

NOTE: Taken from Blake (1984).

repository openings, remedial actions, utilizing available technology, would be taken to mitigate the consequences of their occurrence and, thereby, minimize risks to personnel safety. Furthermore, a microseismic-monitoring system would be used in conjunction with other performance-monitoring techniques in an attempt to predict postexcavation rock bursts. Remedial actions might include destressing highly stressed rock by blasting (Karwoski et al., 1979, pp. 1 through 47), reinforcing the rock with tensioned rock bolts (Saito et al., 1983, p. D-206), or supporting the rock by using fiber-reinforced shotcrete (Barton, 1986).

While some water inflow into excavated openings is anticipated, the volumetric flow rate is expected to be low. Higher water inflows could occur if the excavations encountered local anomalies or a flow top with high permeability; however, directional borehole probing prior to excavation should minimize this possibility. The presence of methane in the openings could occur by virtue of being introduced with water inflow. Adequate ventilation would mitigate these hazards. Physiological and psychological effects on personnel due to high rock temperature could also be controlled by proper ventilation. Each of these potentially hazardous rock characteristics is discussed more fully below.

Excavated opening instabilities

Three methods are commonly used to assess the stability of excavated openings and to estimate roof-support requirements. These include (1) numerical techniques, (2) empirical methods, and (3) monitoring and observation. These methods are expected to be used at the reference repository location to assess rock-support requirements.

Numerical techniques are used to assess stress and deformations around openings, to select room shapes and waste-emplacement configurations, and to assess overall room stability. Numerical techniques are not sufficiently developed to be used directly in the selection of specific rock-support components, but the analysis indicates a need for support requirements.

Empirical methods have been developed by observing the stability of openings under a wide range of conditions and relating this stability to rock characteristics. The adequacy of a specific rock-support method for a rock of given quality is inferred from the stability or instability exhibited by the opening over an extended period of time. Empirical methods are generally employed as a first approximation of rock quality and the associated rock-support requirements.

Two different empirical methods (the geomechanics rock mass rating system (Bieniawski, 1979) and the rock quality system (Barton et al., 1974, pp. 189 through 236)) and laboratory and field test data have been utilized to assess rock mass quality and support requirements within the Cohassett flow interior (see Subsection 6.3.3.2.4). Application of the empirical techniques of Barton et al. (1974) and Bieniawski (1979) by Barton (1986) and Voss (1984), respectively, presented in Subsection 6.3.3.2.4, indicate either rock bolts, shotcrete, or a combination of the two. Rock-support requirements in different areas of the repository would vary, depending on local rock conditions and the period of time that the opening would be routinely occupied by operating personnel. A final determination of required rock support in the repository would be made from information obtained during the exploratory shaft program (see Subsection 4.1.1.6) if the reference repository location were recommended for site characterization.

The empirical methods for support estimates were not based on case histories involving thermal-induced stresses and, therefore, have no specific precedent for examining heated rock masses. However, Barton (1986, Table 6-B, pp. 69 and 72) analyzed the case of thermal-induced stresses on rock-support requirements by increasing the stress-reduction factor in the rock quality system approach. The result was that support requirements for the emplacement rooms increased, but still consisted of a rock bolt and shotcrete system. No support increase was estimated for main access drifts and the shaft area.

Monitoring and observation of excavated opening stability would be undertaken when the exploratory shafts are completed and access to the Cohassett flow is obtained. Direct observation of the rock mass behavior and the excavation-support system under a variety of conditions would be employed as a means of confirming the preliminary predictions made using the numerical techniques and empirical methods discussed above. These observations would include the as-excavated condition of the opening, as well as the heated condition.

Rock bursts

Rock bursts could possibly create hazards during excavation of repository openings. A rock burst can occur in a highly stressed, brittle rock when stored energy in the rock mass is suddenly released. A high-stress environment and brittle rock condition in the reference repository location are indicated from the occurrence of core disking (Lehnhoff et al., 1982, p. 1) and borehole spalling, and are confirmed by hydrofracturing test results (Kim and Haimson, 1982, pp. 54 through 58; Kim et al., 1984b). Thermal-induced rock stresses also might increase the potential for rock bursts. A review by Blake (1984) of the expected conditions during repository excavation and operation indicates that there is a moderate potential for spitting and popping of small pieces of rock (mild rock burst) and a low potential for severe rock bursts, because of the lack of many of the characteristics that would contribute to bursting (particularly high extraction ratio and geologic complexities). Thus, severe rock bursts are not expected at the reference repository location.

Core disking is a phenomenon in which rock cores recovered from a borehole self-fracture into a series of thin disks, similar in appearance to a stack of poker chips. Core disking is normally associated with high levels of in situ stress. Core disking has been observed at various depths in boreholes at the reference repository location and other locations on the Hanford Site.

7 0 1 6 8 1 3 1 2

Borehole spalling is a phenomenon describing the appearance of the wall of a vertical borehole in which wedge-shaped failure zones form on the opposing sides of the borehole wall and the rock in these zones falls loose. Borehole spalling is normally associated with high levels of in situ stress and has been observed in boreholes at the reference repository location and other locations at the Hanford Site.

Hydrofracturing is a method for in situ stress measurement from a borehole and involves fracturing a packed-off segment of a borehole by pressurizing it with water. Although this technique has some uncertainty associated with data interpretation, it is the only accepted method for measuring in situ stress at depths greater than a few meters (feet) from the drilling surface. Hydrofracturing tests at the proposed candidate repository horizons have been performed in four boreholes at the Hanford Site (Kim et al., 1984b). Test results indicate an average horizontal to vertical stress ratio in the Cohassett flow of 2.5:1. Additional data on in situ stresses would be obtained by the overcoring methods during site characterization.

Case history studies show that severe rock bursts are generally not associated with the excavation of isolated openings, but are commonly related to excavation in areas overstressed by adjacent openings or with high rock extraction ratios (Blake, 1972, pp. 1 through 64). However, rock bursts have been experienced in single drift headings (Saito et al., 1983). These rock bursts are generally associated with excavation into a highly stressed area and may occur at the face of an opening or at a point farther back from the face where the stress concentration around the opening reaches a maximum.

Severe rock bursts are generally not expected in the Cohassett flow for the following reasons (Blake, 1984).

First, the rock extraction ratio (the percent of rock excavated) in the current design concept is less than 20 percent and is, therefore, far below the rock extraction ratios encountered in typical mining operations near locations where rock bursts have been observed. Thus, the cumulative stress effect of one repository opening on an adjacent opening is minimized.

Second, it is expected that the closely spaced and interlocking nature of the basalt joints would tend to dissipate strain energy around openings through deformation, resulting in a reduced likelihood of rock bursts. In the event that mild rock bursts are experienced during excavation of repository openings, remedial action could be taken to mitigate the consequences. The methods commonly used are (1) destressing the rock near the face of the opening by blasting the zone of highly stressed rock with a small charge of explosive and (2) reinforcing the rock with tensioned rock bolts, with or without welded wire mesh (Karwoski et al., 1979, pp. 1 through 47).

Deep underground openings in rock other than basalt have been safely excavated in areas that have evidenced core disking and borehole spalling (Saito et al., 1983; Bai et al., 1983).

Water inflow under high pressure

During the excavation of underground facilities, unintentional excavation into localized permeable zones might produce hazardous conditions if large quantities of hot water flow into the excavation. Hydrologic studies have found high water pressure (e.g., approximately 9.6 megapascals (1,380 pound-force per square inch)) in the vicinity of the Cohassett flow. The repository in the Cohassett flow interior is expected to have low permeability (hydraulic conductivity less than 10^{-10} meter per second (10^{-5} foot per day)) and bounded by a more permeable flow top and flow bottom. The flow top and flow bottom provide the most likely source of water inflow into the underground facilities. Geologic features (e.g., abrupt thickening of flow-top breccia, pillow palagonite zones, spiracles, other localized discontinuities, and faults or shear zones) may provide a means of access for water inflow into the repository facilities (see Subsections 3.3.2.1, 6.3.3.2.6, and 6.3.3.2.9). Baker (1985) conducted a preliminary analysis of ground-water flow into a repository. An inflow volume on the order of 0.006 cubic meter per second (100 gallons per minute) is expected. There is a high uncertainty associated with this calculation. Higher water inflows are possible, depending on the feature encountered.

The following precautions can be implemented during design and construction to identify anomalous zones and to mitigate high water inflow if encountered. During excavation, small-diameter holes would be drilled ahead of the excavation to detect any geologic conditions that may produce high water inflows. The final repository design is expected to be flexible enough so that any anomalous zone encountered during exploratory drilling can be further investigated prior to implementing water-inflow-control measures, or continuing the repository development in a more favorable area. Pressure grouting and dewatering are methods that can be used to control high water inflow. In addition to the precautions taken to detect water-bearing zones, the repository design would provide pumping stations and sumps that could pump large quantities of water from the repository. During early construction when pumping stations were being constructed, temporary pumps would be located in the shaft sump to provide the capability of removing water.

Implementation of these precautions is expected to improve safety and reduce risk to an acceptable level for underground personnel.

Presence of gas

The presence of methane gas in an underground facility during construction or operation is a potentially hazardous condition for the health and safety of personnel. Methane is not necessarily associated with basalt, rather, it is dissolved in the ground water. Ground-water samples from the Grande Ronde Basalt at the reference repository location are approximately 50 percent saturated with methane under formation conditions. Methane inflow is expected to be proportional to the quantity of water inflow, permeability of the host rock, and the partial pressure differential between the in situ hydraulic pressure and the atmospheric pressure of the facility. Due to the low permeability of the host rock, the hydraulic pressure increases rapidly with distance away from the openings, limiting the source of methane. Water inflow is expected to reach a steady-state condition with inflows decreasing with time relative to initial water occurrence. Water inflow detection and control measures further reduce the amount of inflow. Liberation of the all available methane from the maximum estimate of water inflow is considered to be an appropriate means of conservatively designing for this potential safety hazard during excavation. Methane inflow estimates based on water inflow estimates are presented in Subsection 6.3.3.2.6.

Precautions would be taken during the design, construction, and operation of the repository to mitigate potential hazards due to the presence of methane. These precautions would include the following:

- The ventilation system for the repository would be designed to provide sufficient airflow to dilute methane concentrations to below 0.25 percent and to exhaust the diluted gas from the underground facility.

- Water inflow into the repository would be controlled or reduced to minimize methane hazards.

- Monitoring of ventilation air for the presence of methane would be conducted to ensure that hazardous concentrations are not allowed to develop.

As additional data are gathered regarding methane in the reference repository location, changes to design and monitoring methods will be made as warranted, so that personnel safety would be maintained. It has not been determined whether, during the operational phase, inactive drifts would be either continuously ventilated or sealed and monitored with no ventilation airflow until the drift is reopened.

High rock temperature

The effect of high rock temperature (51°C (124°F)) on the health and safety of personnel working in underground facilities is potentially an adverse condition (Rockwell, 1984b, p. 10). To mitigate this condition, the following precautions and procedures would be followed.

- A repository ventilation system would be designed (Rockwell and RKE/PB, 1982, p. 58) so that the air temperature and relative humidity in the working areas could be maintained in compliance with the limits set by the American Conference of Government Industrial Hygienists (ACGIH, 1982).

- Emergency egress provisions would be included in the repository design and operating procedures to establish personnel evacuation should ventilation systems fail.

- Periodic medical examinations would be provided for personnel working underground to ensure that health and safety are maintained.

Thus, while heat stress to personnel is a health and safety concern, it can be mitigated by application of safety provisions proven acceptable to the mining industry.

6.3.3.2.11 Conclusion on qualifying condition

The results of the preliminary studies suggest that thickness and lateral extent of the Cohassett flow are expected to be suitable for excavation of a repository. The construction of the repository is achievable using available construction methods and technology. The stability of excavated openings is expected to be maintained without undue risk to the health and safety of personnel using available methods to mitigate safety concerns. The potential for opening instabilities and rock bursts cannot be fully assessed until in situ testing is completed within the Cohassett flow and numerical analyses are conducted and verified. Potentially hazardous conditions, including water inflow under high pressure, presence of gas, and high rock temperatures, are expected to be mitigated and, thus, not create undue risk to personnel. Therefore, the evidence does not support a finding that the reference repository location is not likely to meet the qualifying condition (Level 3).

6.3.3.3 <u>Hydrology (Section 960.5-2-10)</u>

6.3.3.3.1 Qualifying condition

"The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in Section 960.5-1(a)(3) to be met."

6.3.3.3.2 Evaluation process

Evaluation of the geohydrologic setting of the Hanford Site is based on laboratory and field tests, conceptual designs, engineering studies, and construction experience in similar geohydrologic settings. The results of these efforts have been used in conjunction with geologic and hydrologic data to evaluate the suitability of the reference repository location as a potential site for a repository.

Underground openings have been constructed in nonbasaltic media (see Subsection 6.3.3.2.6) and are operating under comparable stresses and hydrologic conditions estimated for the reference repository location. There are no underground openings constructed in basalt of the Columbia Plateau at the depths required for a repository.

Technology proposed for the construction, operation, and closure of the repository is discussed in Subsections 6.3.1.3 and 6.3.3.2. Specifically, Subsections 6.3.1.3.5 and 6.3.3.2.6 present engineering measures within the means of available technology to mitigate potentially adverse conditions, including potentially adverse geohydrologic conditions. Subsections 6.3.3.2.9 and 6.3.3.2.10 discuss water inflow under high pressure. Shaft construction and liners, as well as seals, are addressed in Subsection 6.3.3.2.6. The analysis presented in Subsection 6.3.4.1.2 and the evaluation process for the preclosure system guideline address requirements to be met (Section 6.3.4).

Relevant data, data uncertainties, assumptions, and analyses that were used to evaluate the geohydrologic setting are presented in the specific favorable and potentially adverse conditions of this subsection.

6.3.3.3.3 Favorable condition

"(1) Absence of aquifers between the host rock and the land surface."

Aquifers exist between the Cohassett flow and the land surface; therefore, this favorable condition is not present at the reference repository location.

The principal basalt aquifers exist within selected sedimentary interbeds and basalt flow tops of the upper two basalt formations. Within the Saddle Mountains Basalt, the Rattlesnake Ridge, Cold Creek, and Mabton interbeds are frequent sources of large ground-water quantities, in addition to flow tops of the Elephant Mountain and Umatilla Members (see Fig. 3-6). Flow tops within the Priest Rapids, Roza, and Frenchman Springs Members of the Wanapum Basalt are also known to be aquifers. Fewer aquifers appear to exist within the Grande Ronde Basalt in the northern Pasco Basin. The chemical quality of these ground waters, relative to human consumption and crop irrigation, is outlined in Subsection 6.3.1.1.9.

Within the Pasco Basin, the principal aquifers tapped for large-scale irrigation are also the sedimentary interbeds and flow tops of the Saddle Mountains and Wanapum Basalts.

As described by Gephart et al. (1983) and graphically depicted in Long and Woodward-Clyde Consultants (Long and WCC, 1984), flow-top hydraulic conductivity values are heterogeneous and, therefore, what may be termed an aquifer in one location for a specified use may not qualify as such in a second location. However, the previously identified aquifers in the Saddle Mountains and Wanapum Basalts appear to be a common feature of the Pasco Basin. In addition, an unconfined aquifer of variable hydrologic character overlies the basalts beneath most of the Pasco Basin (see Section 3.3.2). Thus, aquifers exist between the Cohassett flow and the land surface.

6.3.3.3.4 Favorable condition

"(2) Absence of surface-water systems that could potentially cause flooding of the repository."

The reference repository location lies above the flood plain of the Columbia and Yakima Rivers and would not be affected by flooding. A flash-flood potential across the southwest portion of the reference repository location exists from ephemeral Cold Creek. However, any potential inundation of proposed repository surface facilities could be controlled by routine engineering measures and would not affect repository operations. Floodwaters from a probable maximum flood could reach some areas considered for repository facilities. Therefore, this favorable condition is considered not present at the reference repository location.

Section 3.3.1 details the flood history and potential of the Columbia and Yakima Rivers under natural and dam-breach conditions. In addition, it addresses the flash-flood potential for the Cold Creek watershed in which the reference repository location lies. In summary, the land surface elevation within the reference repository location ranges between 190 and 245 meters (625 and 800 feet) above mean sea level. At this elevation, the reference repository location is protected from natural flooding and dam-breach scenarios for the Columbia and Yakima Rivers.

A potential does exist for shallow flash flooding of limited extent within the reference repository location. Analyses suggest that the southwest corner of the reference repository location might be inundated by a probable maximum flood in the Cold Creek watershed (see Fig. 3-29). This is the topographic low point within the reference repository location. The shallowest portions of a probable maximum flood might extend into the area considered for repository support facilities on the surface. Using conservative data inputs, a maximum flood depth of 2.3 meters (7.7 feet) was calculated to occur in the center of the flood channel (Skaggs and Walters, 1981). (The elevation of the valley floor is approximately 195 meters (640 feet) along the southwest corner of the reference repository location.) Theoretically, the recurrence interval of a probable maximum flood cannot be defined. The duration of this flood would be short.

The surface characteristics of the reference repository location are addressed in Subsection 6.3.3.1.

6.3.3.3.5 Favorable condition

"(3) Availability of the water required for repository construction, operation, and closure."

Ample water supplies are available for repository construction, operation, and closure; therefore, this favorable condition is present.

Water quantity estimates for the repository are provided in the 1982 conceptual design (RKE/PB, 1983). The average daily water demand for facility support during repository construction, operation, and closure has been estimated at 2.6 cubic meters (approximately 700 gallons) per minute (Gimera, 1983). The water would be supplied to the repository from the Columbia River via either a new water line approximately 12 kilometers (7.4 miles) long or a pipeline from the water-distribution system in the 200 Areas.

The surface flow of the Columbia River averages 3.2×10^5 cubic meters (8.4×10^7 gallons) per minute. Water usage for waste-management and chemical processing activities in the 200 Areas is approximately 42 cubic meters (1×10^4 gallons) per minute (DOE, 1982e). This water is withdrawn from the Columbia River north of the reference repository location. The general layout of the water-distribution system for the 200 Areas is discussed in Summers (1975). Alternate water supplies are also available from the unconfined and confined aquifers.

Water demand from all repository operations would be approximately 6 percent of the present water usage for waste-management and chemical-processing activities at the Hanford Site. Excess water accumulated in the repository would be pumped to the surface and stored in retention ponds.

6.3.3.3.6 Potentially adverse condition

"Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure."

The technology to control ground water during repository construction, operation, and closure is reasonably available. Therefore, this potentially adverse condition is not expected to be present at the reference repository location.

Access shafts to the repository would be drilled using available drilling technology. Subsection 6.3.3.2.6 presents an extensive discussion of the engineering methods proposed for shaft construction, and concludes that shaft construction at the reference repository location can be accomplished using reasonably available technology. The ground-water inflow from penetrated aquifers can be controlled by drilling mud. After hole drilling is complete, a steel casing would be lowered into the hole. The annulus between the casing and rock would be filled with cement grout. The function of the grout would be to seal off aquifers and to support structurally the casing.

Control of ground-water inflow into the underground facility will be accomplished using control of the location of the excavations relative to water-producing zones and existing technology associated with grouting and sealing. Subsection 6.3.3.2.6 discusses the methods and technologies available for control of ground-water inflow during repository construction, operation, and closure, and concludes that the ground-water conditions at the reference repository location would not require complex engineering beyond reasonably available technology.

Ground-water inflow into the repository has been estimated by Baker (1985) to be on the order of 0.006 cubic meter per second (100 gallons per minute) based on the repository excavations located in the Cohassett flow interior. Higher localized inflows are expected in regions of poor rock quality. The worst case for ground-water inflow would occur if the excavation intersected a flow top or flow bottom. Baker (1985) performed a preliminary calculation on a worst-case condition and concluded that ground-water inflow could reach approximately 0.20 cubic meter per second (3,400 gallons per minute). There is a large uncertainty associated with these calculations. Intersection of a flow top or flow bottom is considered unlikely, because the Cohassett flow interior is sufficiently thick to provide adequate flexibility in locating the depth of the repository and to provide a buffer of undamaged rock between the excavations and the flow top. The thickness of the Cohassett flow interior is discussed in Subsections 6.3.1.3.3 and 6.3.3.2.3. Also during construction, exploratory boreholes will be drilled in advance of excavation to identify any zones of abnormal water production. These zones will be grouted as necessary to ensure safe working conditions.

6.3.3.3.7 Disqualifying condition

"A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure."

Construction data, case history studies of underground construction projects, and understanding of the basalt geohydrologic environment suggest that the ground-water conditions likely encountered in basalt during exploratory shaft construction and repository construction, operation, or closure will require reasonably available technology. Therefore, the evidence does not support a finding that the reference repository location is disqualified (Level 1).

Shafts to the Cohassett flow would penetrate several aquifers (see Subsection 6.3.3.3.3). Potential ground-water inflow can be controlled using available techniques (e.g., grouts and muds for blind-bored shafts). Shaft completions through aquifers would involve steel liner emplacement and grout seals (refer to Subsection 6.3.3.2.6).

The waste-emplacement rooms of a repository or test rooms of the exploratory shaft would be constructed within the interior of the Cohassett flow. Basalt flow interiors are expected to have a low permeability (see Subsection 3.3.2.1.1) and, therefore, low ground-water inflow. Water seepage into the excavated openings is expected to occur along fracture sets rather than to be distributed uniformly along the openings. Large water inflows could result from unintentional penetration of high-permeability zones; however, exploratory drilling in advance of excavation should minimize such a possibility. Available grouting and dewatering technology can enable the safe completion of underground construction should localized zones of high permeability be encountered within a flow interior.

The sections and subsections listed below address the availability of engineering technology for the safe construction of shafts and drifts under expected ground-water conditions and rock characteristics.

Sections	Topics
4.1.1.6	Exploratory shaft(s) construction.
5.1 and 6.3.1.3.5	Engineering technology available for repository activities.
6.3.3.2.6	In situ characteristics and conditions requiring measures beyond reasonably available technology.
6.3.3.2.9	Geologic features possibly encountered.
6.3.3.2.10	Rock characteristics related to rock bursts, water inflow, gas inflow, and high working temperatures.

Discussions of the range of possible rock conditions expected to be encountered and the technology available to mitigate any resulting adverse conditions are addressed throughout Subsections 6.3.1.3 and 6.3.3.2. These subsections also address the uncertainty in available knowledge regarding the existence and significance of some stratigraphic and structural features that may contribute to ground-water flow.

6.3.3.3.8 Conclusion on qualifying condition

A final conclusion on the qualifying condition for hydrology cannot be made; however, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3). Factors that support this preliminary finding are summarized below.

- The reference repository location lies above the flood plain of the Columbia and Yakima Rivers and would not be affected by river flooding.
- Ample water supplies are available for repository construction, operation, and closure.
- Technology to control ground water during repository construction, operation, and closure is reasonably available.

- Ground-water conditions likely to be encountered in basalt during exploratory shaft construction and repository construction, operation, or closure will require only available, or reasonably available, technology.

Specific uncertainties related to the supporting factors are listed below.

- There are no deep underground openings constructed in basalt; therefore, the available information to determine the geomechanical and geohydrologic characteristics of deep basalt has been derived from in situ and laboratory tests.

- There does exist a potential for Cold Creek flash flooding of limited extent within the reference repository location.

6.3.3.4 Tectonics (Section 960.5-2-11)

6.3.3.4.1 Qualifying condition

"The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in Section 960.5-1(a)(3) can be met."

6.3.3.4.2 Evaluation process

The tectonic processes that have operated on the Columbia Plateau over the past few hundred years are the same processes expected to be operating during repository construction, operation, and closure. The data gathered to assess these tectonic processes include (1) stratigraphic and structural information gathered from geologic maps, interpretive cross sections obtained by direct observation at the ground surface and (or) borehole data, geophysical interpretation of magnetic, gravity, seismic reflection, seismic refraction, and magnetotelluric surveys and (2) historical seismicity derived from published catalogs and newspapers, instrumental seismicity from records of earthquake locations, and focal mechanisms.

A summary of the tectonic setting is found in a report by Caggiano and Duncan (1983). See Section 3.2.3 and Subsection 6.3.1.7 for additional details.

Interpretations of the tectonic stability within the geologic setting of the reference repository location are preliminary, because (1) interpretations of subbasalt stratigraphy and structure are too preliminary to permit adequate testing of tectonic models, (2) preliminary monitoring of seismicity at repository depth in the reference repository location is only beginning, (3) reconnaissance geologic mapping is complete, but detailed studies of specific structures and interpretation of geophysical anomalies in and near the area of the reference repository location are ongoing, and (4) kinematic analyses of fold development and of the relationship of folding to faulting remain to be completed.

The adverse tectonic condition that could preclude development of a repository is that of an active fault (either seismically active or actively creeping). Active faults do not appear to be present in the reference repository location (see Section 3.2.3). If such faults occurred, they could contain fault gouge and ground water that might affect the ease of excavation and the volume of water to be pumped from an excavation. Additional rock-support measures might be needed in such zone(s), but these problems are expected to be accommodated during construction (see Subsection 6.3.3.2).

Columbia River Basalt Group volcanism ceased approximately 6 million years ago (McKee et al., 1977). The youngest flow in the reference repository location area is the 10.5-million-year-old Elephant Mountain Member of the Saddle Mountains Basalt (Myers, 1981). There are no known hot springs in or near the reference repository location, nor is the area one of high heat flow (Caggiano and Duncan, 1983). This evidence suggests that renewal of Columbia River Basalt Group volcanism is extremely unlikely during construction, operation, and closure of a repository in the reference repository location. Air-fall ash generated during any future eruptions of volcanoes in the Cascade Range (e.g., Mount St. Helens is located approximately 180 kilometers (112 miles) west of the reference repository location) should not affect underground construction and should pose only minimal disturbance for a limited period for surface operations. Thus, volcanism is not expected to be a major concern in constructing a repository in the reference repository location.

6.3.3.4.3 Favorable condition

"The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities."

A 0.25-g peak horizontal ground acceleration has been recommended as a starting point for the design of surface facilities for a repository in the reference repository location. Even allowing that this value might increase, the design for surface facilities for a repository in basalt likely would still be less than for some nuclear powerplants west of the Cascade Range and significantly less than for those in California. However, the favorable condition is judged to be not present, because the seismic design for facilities in the reference repository location would not be significantly less than that for many other nuclear facilities.

The basis for the not present position is that approximately 90 percent of nuclear reactors in the United States have a safe shutdown earthquake acceleration value less than or equal to 0.20 g, which is less than the acceleration recommended for a repository in the reference repository location. The seismic design for a repository in basalt will not, in all likelihood, incorporate ground motions in excess of what seismic design has successfully accommodated elsewhere in the United States.

Deformation of the Columbia River Basalt Group in the central Columbia Plateau has been proceeding at long-term, average low rates under nearly north-south, nearly horizontal compression for at least 15 million years (Caggiano and Duncan, 1983). The pattern of folding accompanied by faulting appears to have been established by Miocene time, but an exact mechanical model of deformation has not been developed. It has been argued that faults are a cause and a consequence of folding (Price, 1982; NRC, 1982), based mostly on the spatial arrangement and geometric character of anticlinal structures. Data do not permit determination of slip-recurrence rates on most faults; however, the pattern and timing of deformation as interpreted suggest that slip rates of faults during late-Cenozoic time have been low. Data have been used to determine slip rates for potentially active faults in the central Columbia Plateau (i.e., the Central fault on Gable Mountain and the Rattlesnake-Wallula alignment). These data support the interpretation of a low rate of deformation. Using data obtained during drilling and trenching, the slip rate for the Central fault was determined to be approximately 0.005 millimeter (0.0002 inch) per year (PSPL, 1982). Based on tectonic models of Bentley (1980), Davis (1981), and Laubscher (1981), the U.S. Nuclear Regulatory Commission (NRC, 1982) calculated a slip rate of approximately 0.01 millimeter (4 x 10^{-4} inch) per year for the Rattlesnake-Wallula alignment. This pattern of deformation suggests that earthquakes would be relatively small and recurrence rates generally long compared with active tectonic regimes (e.g., the plate boundary regime in California). The level and distribution of instrumentally recorded earthquakes over the past 14 years support this interpretation (Rohay and Davis, 1983).

There have been numerous nuclear facilities for the processing, storage, and disposal of nuclear waste for defense and commercial purposes at the Hanford Site since 1943 (ERDA, 1975). These nuclear facilities have been constructed and operated in a safe manner during this 43-year period, and have not been adversely affected by tectonism.

The Washington Public Power Supply System operating plant WNP-2 received its operating license in December 1984. The safe shutdown earthquake for this plant is a magnitude 6.5 that has been placed on the Rattlesnake-Wallula alignment at a distance of 20 kilometers (12 miles) from WNP-2 and at a depth of 15 kilometers (9 miles) (NRC, 1982) (see Fig. 3-19 and 3-37). The corresponding zero-period horizontal ground acceleration used to anchor response spectra for this plant is 0.25 g. This design acceleration is less than for those nuclear plants located west of the Cascade Range in Washington and Oregon and considerably less than those at Diablo Canyon and San Onofre in California. Ninety percent of the nuclear powerplants in the United States have a safe shutdown earthquake acceleration value of less than or equal to 0.20 g.

6.3.3.4.4 Potentially adverse condition

"(1) Evidence of active faulting within the geologic setting."

This potentially adverse condition appears to be present in the geologic setting. Faults that may have been active during the Quaternary Period exist in the Columbia Plateau.

The age of movement of the many faults on the Columbia Plateau remains to be determined. Faults that may be active include the Central fault on Gable Mountain, which is located 9 kilometers (5 miles) northeast of the reference repository location (PSPL, 1982; NRC, 1982), and the area of Wallula Gap eastward to the Hite fault (WPPSS, 1981), which is located more than 80 kilometers (50 miles) southeast of the reference repository location (see Fig. 3-19). Active faulting is discussed in Subsection 6.3.1.7.4.

6.3.3.4.5 Potentially adverse condition

"(2) Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits."

The effects from recurrence of a large historical earthquake on subsurface facilities at the reference repository location are unknown, but the low to moderate seismicity of the Columbia Plateau should not result in ground motion at the site that would be in excess of reasonable design limits. Man-induced seismicty (e.g., quarry blasts) has not produced ground motions in the reference repository location in excess of reasonable design limits. Therefore, it is assumed that this potentially adverse condition is not present within the geologic setting of the reference repository location.

The maximum reported earthquake within an 80-kilometer (50-mile) radius of the reference repository location was a magnitude 4.4 on Royal Slope, the south flank of a Yakima fold approximately 35 kilometers (22 miles) north of the reference repository location. A historically reported earthquake on November 1, 1918, near Corfu, Washington (approximately 30 kilometers (19 miles) northeast of the reference repository location) (see Fig. 2-9), is listed as a Modified Mercalli Intensity V-VI, and may have been as large as magnitude 4.5 (Myers, Price et al., 1979; Rohay and Davis, 1983). Ground motion generated by such events at these distances from the reference repository location is not believed to have produced any significant vibratory ground motion in the reference repository location.

In developing the seismic design for the Washington Public Power Supply System operating plant WNP-2 on the Hanford Site (approximately 18 kilometers (11 miles) southeast of the reference repository location) (see Fig. 3-37), a maximum possible earthquake was determined for the Rattlesnake-Wallula alignment, based on its assumed capability, assumed continuous length, and type of fault. A magnitude 6.5 earthquake with a recurrence of approximately 50,000 years or more (Slemmons, 1982) corresponds to a 0.25-g zero-period horizontal ground acceleration at the WNP-2 site. This value was used to anchor response spectra used in the design of structures, components, and facilities. This same acceleration was used in the design of the Fast Flux Test Facility on the Hanford Site (see Fig. 3-37). The seismic design of WNP-2 and the Fast Flux Test Facility indicates that ground motion at the Hanford Site is expected to be within reasonable design limits.

Empirical data indicate that mines and tunnels generally are not adversely affected by earthquakes large enough to cause damage (often severe) to surface buildings and facilities. Detrimental effects are noted only if the rupturing fault intersects the mine or tunnel. However, the behavior of springs and water inflow into mines following earthquakes suggests that some changes in ground-water flow may be brought about by fault rupture. During site characterization, design earthquakes and ground motions would be determined so that potential effects of vibratory ground motion and changes in ground-water flow can be assessed.

Man-induced seismicity through quarry blasts, geophysical investigations, and construction projects has occurred on the Hanford Site. Ground motions from these activities are not expected to exceed reasonable design limits.

6.3.3.4.6 Potentially adverse condition

"(3) Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity."

The historic seismicity of the Columbia Plateau is low to moderate, based on over 100 years of historic earthquake record (see Subsection 2.1.1.3 and Section 3.2.4). This record is judged sufficient to suggest that larger-than-historic events (i.e., greater than magnitude 5.75) are not likely to occur during the preclosure period. This interpretation includes studies used in seismic design for the Washington Public Power Supply System operating plant WNP-2 and the Skagit-Hanford Nuclear Project, but does not consider design events (i.e., safe shutdown earthquakes and design basis earthquakes) that have a low probability of occurrence. Also factored into the interpretation are the rates, patterns, and timing of deformation of the Columbia River Basalt Group. It appears that this potentially adverse condition is not present within the geologic setting of the reference repository location.

As part of the operating license for the Washington Public Power Supply System operating plant WNP-2 at the Hanford Site, the U.S. Nuclear Regulatory Commission concluded that the Rattlesnake-Wallula alignment (see Subsection 3.2.3.7), located along the southwestern boundary of the Pasco Basin, may be capable of a magnitude 6.5 earthquake along segments of the fracture (NRC, 1982). This earthquake is larger than any historical or instrumentally recorded earthquake on the Columbia Plateau. The recurrence interval for an earthquake of magnitude 6.5 or larger was estimated to be very large (greater than at least 50,000 years) (Slemmons, 1982). However, this appears conservative, since the youngest observed faulted sediments along the fracture are 70,000 years old and portions of the fracture have apparently not been faulted for at least 12 million years.

6.3.3.4.7 Disqualifying condition

> "A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation or closure."

Engineering measures could be used, if needed, in an exploratory shaft or repository. This statement is based on the low probability of ground motion that could adversely affect a repository in the reference repository location during the preclosure period. Therefore, the evidence supports a finding that the reference repository location is not disqualified on the basis of that evidence and is not likely to be disqualified (Level 1).

The low probability of ground motion is based on the following evidence, which has been summarized from discussions on tectonic disqualifying conditions.

- The seismicity of the Columbia Plateau is low to moderate (see Subsection 2.1.1.3 and Section 3.2.4).
- The recurrence rate of moderate-size earthquakes is long (see Subsection 6.3.1.7.5).
- The reference repository location was sited away from areas of major faulting (see Section 2.2).
- The potential for diapirism or igneous activity is low (see Subsection 6.3.1.7.3).

6.3.3.4.8 Conclusion on qualifying condition

A final conclusion on the preclosure qualifying condition for tectonics cannot be made until site characterization is complete. However, the evidence does not support a finding that the site is not likely to meet the preclosure qualifying condition for tectonics (Level 3).

This interpretation is based on (1) the rate, pattern, and timing of deformation of the Columbia River Basalt Group, (2) the low to moderate seismicity along with the aerial distribution and size of earthquakes, (3) the low heat flow and unlikely renewal of basaltic or other volcanism in the central plateau, and (4) the likely ability of engineering design and construction techniques to deal with the characteristics of the natural environment. Studies used to arrive at this interpretation are summarized in Caggiano and Duncan (1983) and include stratigraphic and structural investigations, seismic-monitoring and seismological investigations, geophysical investigations and anomalies, and geodetic monitoring. Deformation has followed a pattern established at least 15 million years ago in Miocene time in which structures have been developing under nearly north-south, nearly horizontal compression at long-term, average low rates of strain. The pattern of developing structural relief during eruption of the Columbia River Basalt Group from at least 14.5 to 10.5 million years ago apparently continues to the present. Projection of the growth rates of major anticlinal folds in the Saddle Mountains and Rattlesnake Mountain from the Miocene accounts for the present elevation of basalt flows in these two Yakima fold ridges. The size, pattern, and distribution of earthquakes in the central Columbia Plateau along with focal mechanism solutions suggest continuing strain under nearly north-south, nearly horizontal compression. Eight surveys since 1972 of a trilateration array across the Hanford Site suggest compression at very low rates compatible with geologically determined rates of deformation, although the data are barely beyond the limits of error of the instruments used to measure changing line lengths (Rohay and Davis, 1983; Prescott and Savage, 1984).

Although the interpretation is one of continuing deformation under nearly north-south, nearly horizontal compression at long-term, average low rates, the possibility of shorter periods in which deformation proceeded at higher rates (i.e., a more episodic pattern and rate of deformation compared with a long-term, average low rate) cannot be dismissed at this time. The rate and timing of deformation in other Yakima folds need to be confirmed, as does the low rate of strain determined geodetically. Instrumental monitoring of shallow microearthquakes in the reference repository location needs to be conducted to determine the recurrence of microearthquakes in the reference repository location and probable levels of ground motion for use in design of subsurface facilities. The relationship of folding to faulting as well as the relationship of deformation in basalt to subbasalt structure need to be determined as a check on the possible episodicity of deformation.

6.3.4 PRECLOSURE SYSTEM GUIDELINE (Section 960.5-1)

6.3.4.1 Ease and cost of construction, operation, and closure (Section 960.5-1(a)(3))

6.3.4.1.1 Qualifying condition

"Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options."

6.3.4.1.2 Evaluation process

The preclosure system guideline on the ease and cost of siting, construction, operation, and closure is ranked lowest in importance among the three preclosure system guidelines, because it does not relate directly to the health, safety, and welfare of the public or the quality of the environment. The elements pertinent to this guideline are (1) site characteristics that affect siting, construction, operation, and closure, (2) engineering, materials, and services necessary to conduct these activities, (3) Federal regulations that establish the requirements for these activities, and (4) repository personnel at the site during siting, construction, operation, or closure.

The pertinent technical guidelines are Sections 960.5-2-8, 960.5-2-9, 960.5-2-10, and 960.5-2-11 in the General Siting Guidelines (DOE, 1984a).

This guideline would not be met if a large number of special measures were necessary for such reasons as (1) the site had unsuitable surface features and the characteristics of the host rock required technology beyond that available at reasonable cost, (2) the hydrologic conditions at the site could limit the effectiveness of repository seals or cause flooding in the underground workings, or (3) the potential for tectonic activity required unreasonable or infeasible design features to protect the workers or the public.

To establish that the site meets this system guideline and the associated technical guidelines, it is necessary to have detailed, site-specific data, most of which can be collected only during site characterization, and analyzed during advanced repository designs. Nonetheless, from the qualitative and quantitative evaluations reported earlier in this section for the technical guidelines, it is possible to make a judgment about the degree of confidence with which the site will indeed be shown to comply with this system guideline.

Surface facilities, repository access shafts, and repository drifts will be constructed using available mining and drilling technology (see Subsection 6.3.3.2.6). A highly skilled labor force for construction of nuclear facilities is available in the Tri-Cities area, with the exception of miners (see Subsection 6.2.1.7.8). Miners will need to in-migrate.

The high-temperature environment at repository depth would require ventilation and air refrigeration to maintain a suitable working environment. Grouting would be used to control water inflow; excess water would be pumped to the surface. These are characteristic features of deep mines. Studies are under way to determine technology requirements to maintain stable tunnels over the life of the repository. Repository closure probably would include backfilling the waste-emplacement rooms with crushed basalt, backfilling portions of the access and ventilation drifts, and sealing of shafts and boreholes with backfill materials of low hydraulic conductivity. Handling and performance testing will be conducted to determine the best materials to use. Sealing of the access shafts may also include use of concrete plugs, grout curtains, or other components whose performance would be demonstrated by testing and analysis. Constructibility of such components would be demonstrated, if necessary, by testing.

The estimated total life-cycle cost for a repository at the reference repository location is 12.3 billion dollars (in 1984 dollars). This includes costs for development and evaluation (1.5 billion dollars), construction (2.3 billion dollars), operation (8.3 billion dollars), and decommissioning (0.2 billion dollars). The development and evaluation estimate includes costs for site characterization, repository conceptual and license application design, and technology development. The construction estimate includes costs for repository final procurement and construction design and the construction of all surface facilities and a limited number of underground waste-emplacement rooms and corridors. The operations estimate includes costs for the construction of the remainder of the underground facilities, the emplacement of the waste, and the caretaker and backfilling activities. The decommissioning estimate includes costs for shaft sealing and decontamination and dismantling of the surface facilities. These costs are discussed further in Chapter 7.

6.3.4.1.3 Conclusion on qualifying condition

A final conclusion on the qualifying condition for preclosure ease and cost of construction, operation, and closure cannot be made until site characterization is complete. However, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3). Two factors that support this preliminary finding are summarized below.

- Surface facilities, repository access shafts, and repository drifts would be constructed using available mining and drilling technology.

- Technology to control ground water during repository construction, operation, and closure is reasonably available.

Specific uncertainties related to the above factors include the following:

- Miners are not available in the Tri-Cities area and would need to in-migrate (see Subsection 6.2.1.7.8).

- Studies are under way to determine technology requirements to maintain stable drifts over the lifetime of the repository.

- Handling and performance tests would be conducted to determine the best backfilling materials to use.

- Based on the available site information and design work completed to date, preliminary cost estimates have been developed for the repository described in Chapter 5. These estimates were developed as part of the U.S. Department of Energy annual evaluation of the adequacy of the 1-mill per kilowatt-hour fee for disposal services and do not represent final cost estimates. More definitive estimates will be completed when more detailed designs and site-characterization data become available.

6.3.5 CONCLUSION REGARDING THE SUITABILITY OF THE SITE FOR SITE CHARACTERIZATION

On the basis of the findings stated in the preceding discussions of individual guidelines and made in accordance with Appendix III of the General Siting Guidelines (DOE, 1984a), it is concluded that the evidence does not support a finding that the reference repository location is disqualified and does not support a finding that the reference repository location is not likely to meet the qualifying conditions.

6.4 ANALYSES SUPPORTING THE COMPARISON WITH SYSTEMS GUIDELINES

The planning and impact chapters in this environmental assessment (Chapters 4 and 5) have provided an overview of the scope, extent, and potential impact of site-characterization and repository-development activities. The preceding sections of Chapter 6 have presented analyses, on a guideline-by-guideline basis, of the suitability of the reference repository location for site characterization. Section 6.4 provides the reader with an overview of the analytical methods used by the U.S. Department of Energy to (1) provide a preliminary assessment of site suitability, (2) identify sensitive parameters or areas that require further analysis during site characterization, (3) guide test program development and site-characterization activities, and (4) help guide the engineering design activities in identifying and mitigating problems important to safety or functioning of the repository.

6.4.1 PRECLOSURE SYSTEM GUIDELINES ANALYSES

6.4.1.1 Scope

Preclosure performance assessment considers the repository operating period, which consists of waste transport and emplacement, possible waste retrieval, and backfilling and sealing of the repository. The objective of such performance assessment activities is to assure regulatory compliance to occupational radiation exposure and potential release of radionuclides to the environment, as well as other safety-related aspects, during repository construction, operation, and closure or possible retrieval. Normal operating conditions and abnormal or accident events are considered in a preclosure performance assessment, which allows identification of sensitive areas. In general, the preclosure performance assessment involves the identification of specific requirements necessary to meet regulatory criteria and the performance of safety analyses to assure compliance with overall repository performance criteria. Safety analysis involves identification of hazards, analysis of risks to health and safety, and specification of preventive or mitigative measures to reduce or eliminate risks.

Assessment of preclosure performance is an iterative process of safety analysis during each repository and waste package design phase. As the design evolves and operating procedures are developed, the safety analysis techniques become more detailed and more quantitative. Results then become inputs to succeeding phases of design and procedure development, either requiring changes in, or confirming the acceptability of, repository design and operating procedures.

6.4.1.2 Safety analysis methodology

The performance goals and acceptance criteria relating to public and occupational health and safety for repository operations are derived from applicable Federal, State, and local regulations and guidelines. Some criteria applicable to the preclosure period are expressly written for a nuclear waste repository (e.g., 10 CFR 60 (NRC, 1985a), 40 CFR 191 (EPA, 1985)). Other criteria are derived from regulations for related nuclear (10 CFR 20 (NRC, 1985b)) or non-nuclear facilities and operations (e.g., Occupational Safety and Health Administration, Mine Safety and Health Administration). Criteria take the form of requirements for subsystems, structures, and components, general safety guidelines.

Applicable regulatory criteria relating to public and occupational health and safety during the preclosure period are specified directly, or by reference, in 10 CFR 60 (NRC, 1985a). Requirements invoked by reference in 10 CFR 60.111(a) pertain to protection against radiation exposure and release of radioactive material. The requirements are listed below.

- 10 CFR 20.101—Permissible radiation dose per calendar quarter for individuals in restricted areas (i.e., where access is controlled by the licensee for purposes of protection of individuals from exposure to radioactive materials) is 1.25 rems for the whole body, head and trunk, active blood-forming organs, lens of eyes, and gonads, 18.75 rems for hands and forearms, feet and ankles, and 7.5 rems for the skin of the whole body.

- 10 CFR 20.103--Limits on exposure of individuals to concentrations of radioactive materials in restricted areas are specified in 10 CFR 20 Appendix B (Table I, Column 1, pp. 20-15 through 20-25).

- 10 CFR 20.105--Permissible levels of radiation in unrestricted areas (i.e., where access is not controlled by the licensee for purposes of protection of individuals from exposure to radioactive materials) are limited to 0.5 rem per calendar year.

- 10 CFR 20.106--Limits of radioactivity in effluents to unrestricted areas are specified in 10 CFR 20 Appendix B (Table II, pp. 20-15 through 20-25).

- 40 CFR 191, Subpart A--The combined annual dose equivalent to any member of the public from operations of the repository shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, or 25 millirems to any other organ.

Design criteria specified for safety during the preclosure period are prescribed by the U.S. Nuclear Regulatory Commission to provide reasonable assurance that the radiation exposure and radiological release requirements contained in 10 CFR 20 (NRC, 1985b) and 40 CFR 191 (EPA, 1985) are met. The requirements are listed below.

- 10 CFR 60.131(a)--The repository operations area shall be designed to limit concentrations of radioactive material in the air, limit and control access, provide shielding, monitor and control dispersal of radioactive contamination, and warn operators of significant increase in radiation levels in air and effluents.

- 10 CFR 60.131(b)--Structures, systems, and components important to safety (i.e., essential to prevention or mitigation of an accident that could result in violation of 10 CFR 20.105) shall be designed against the effects of natural phenomena, equipment failure, fires, and explosions. This requirement includes designing facilities to assure safe and timely response to emergencies and incorporating redundancy into systems important to safety. Additional specific provisions apply to inspection, testing, maintenance, criticality control, instrumentation and control systems, compliance with the Federal Mine Safety and Health Act of 1977, and requirements for shaft conveyances used in radioactive waste handling.

- 10 CFR 60.132--Surface facilities shall be designed to handle waste safely, and to monitor and control release of radioactive materials in effluents and ventilation exhaust air. Waste-treatment facilities shall be provided to process any waste generated at the site, and facilities shall be designed to facilitate decontamination and decommissioning.

- 10 CFR 60.133--The underground facility shall be designed to confine the effects of flooding, fires, and explosions, to provide for control of water or gas intrusions, and to minimize potential for collapse of openings. Separate underground ventilation systems shall be provided for excavation and waste-emplacement areas, and shall be designed to function during normal and accident conditions.

- 10 CFR 60.135--The waste package shall not contain explosive or pyrophoric materials. The waste container shall be designed to maintain containment during transportation, emplacement, and retrieval. Radionuclides shall be immobilized in a solid matrix, which is noncombustible.

Applicable requirements are translated directly into specific design criteria, construction and operating specifications, or procedures. Where overall performance goals and system performance criteria exist, safety analyses are used to assess compliance. Similarly, safety analyses may be performed to confirm compliance with the requirements for design, construction, or operations, or to assess the effect of proposed deviations from such requirements.

Such safety analyses follow a general procedure, consisting of the following:

- Development of a systems description of the repository facility and its operational characteristics.

- Identification and characterization of potential hazards associated with normal operations.

- Selection and characterization of accident or abnormal scenarios caused by internal or external events.

- Risk analysis of the postulated event.

- Development of recommendations for preventive and mitigative measures.

6.4.1.3 Description of safety analysis methodology

6.4.1.3.1 System description

Safety analysis requires a detailed description of the process or system under evaluation. The system description is based on available design and test data that can be used to characterize repository construction, operation, decommissioning, and possible retrieval operations under normal operational conditions. The system description is developed in sufficient detail to serve as the basis for subsequent safety analysis and is expected to be updated after each major design phase is completed. Flow diagrams are utilized to describe repository operations; typically, they identify the associated personnel requirements and duration of each process. These flow diagrams allow an evaluation of occupational exposure to radioactive material and nonradiological hazards. Processes evaluated in this manner for potential radiation exposure and radiological release during the operating and decommissioning periods include receiving, inspecting, handling, transporting, and emplacing nuclear waste, monitoring and possible retrieval of waste prior to permanent closure, and backfilling and sealing of pathways to the emplaced waste.

6.4.1.3.2 Characterization of normal operations hazards

This effort focuses on the identification and evaluation of subsystem operations that involve potential hazards. Hazardous material and dispersal mechanisms that can impact safety under normal operating conditions are identified. Each safety hazard is then classified into categories (e.g., radiological, chemical, occupational, environmental). A review of the repository design is performed to assure compliance with established safety criteria. Hazards that warrant further quantitative analysis of associated consequences are identified. Prior to formal consequence analysis, preventive and (or) mitigative measures that can be incorporated as alternative design concepts or improved operating procedures are developed.

6.4.1.3.3 Selection and characterization of accident scenarios

Accident scenarios that may impact system safety are identified and described as a part of preclosure safety analysis. Scenarios considered are those that can result in potential occupational radiation exposure or offsite radiological release. Accident conditions that may be created by events induced within and external to the facility are examined. Mining accidents, severe environmental conditions, and man-induced events are considered. Failure modes and effects and fault-tree analyses are used to evaluate accident conditions resulting from equipment failure and (or) operator error within the facility.

6.4.1.3.4 Risk analysis

Potential consequences of a particular chain of events are evaluated and quantified. The consequence analysis includes evaluation of contaminant source terms, transport pathways, and radiation dose. Source terms are quantified through detailed analysis of previously described accident scenarios. Release characteristics will depend on the type of initiating event (e.g., fire, explosion) and the fraction of waste inventory involved.

Within the facility, transport pathways are determined by evaluating ventilation system performance, radioactive waste system capabilities, and expected response of monitoring systems and personnel to accident conditions. Environmental pathways through air and water are evaluated through the use of models. Radiation doses to the public and repository personnel are calculated for direct exposure, inhalation, ingestion, or immersion.

Broad estimates of occurrence probabilities are assigned to accident-initiating and succeeding events. Analysis of these probabilities and the consequences of corresponding events yields a measurement of risk that can then be used in a risk-management plan to support recommendations for risk reduction.

6.4.1.3.5 Recommendation of preventive and mitigative measures

The preclosure safety analysis culminates in the confirmation of acceptability of the existing or proposed design or in the recommendation of specific means of improving the repository design. Preventive measures are used to reduce the possibility of an accident occurring; mitigation measures are designed to minimize the consequences of an accident and facilitate recovery from an accident. Recommendations are made for revising pertinent safety design criteria, identification of alternate design concepts that meet functional requirements with greater safety, and (or) modifying operating procedures. Because this task represents an integration of safety analysis studies with the repository design, the final list of recommendations will be the result of a cooperative effort between performance assessment activities and the repository architect-engineer and will be targeted to reduce overall preclosure safety risk.

6.4.1.4 Evaluation of preclosure repository performance

Potential radiological hazards resulting from normal and abnormal repository operations are summarized below. Nonradiological hazards addressed in this environmental assessment deal primarily with mine safety (see Section 5.2.4 and Subsection 6.3.3.2).

6.4.1.4.1 Normal operating conditions

Waste-handling operations pose some potential for radiation exposure to repository workers. Radiation exposure hazards have been identified, along with existing and recommended design features and procedures to minimize this risk (RKE/PB, 1983). Design features that eliminate or reduce these risks include shielding, radiation monitors and alarms, access control, control of waste-transport paths, provision of hot cell seals, and adequate design margins in hoisting systems. Design features and operating procedures would reduce the risk of radiation exposure to personnel.

6.4.1.4.2 Analysis of releases under routine operations

The conceptual design for a repository in basalt is based on the receiving and handling of prepackaged spent fuel and high-level waste (see Section 5.1). Radioactivity would not be released from repository surface facilities unless externally contaminated or leaking containers were received. However, as required by the Nuclear Waste Policy Act of 1982 (enacted after completion of the 1982 conceptual design) (RKE/PB, 1983), repository facilities will be required to receive and package spent fuel assemblies as the primary waste form. The storage and handling of spent fuel assemblies present a much greater potential for routine release of radioactivity than repository operations involving prepackaged spent fuel or high-level waste. Analysis of the potential releases from the handling of spent fuel is used to approximate the expected dose to members of the public from routine repository operations.

Following receipt, spent fuel assemblies would be disassembled and the individual fuel rods consolidated in a closely packed array in a welded steel container. The principal mechanism for potential release of radioactivity during operations is expected to occur during disassembly. This operation may be performed by pulling the rods from the end fittings, mechanically sawing the guide tubes, or by the use of a laser cutting technique. Results of a study on the consequences of fuel rod disassembly were used to approximate the radiological impacts of a spent fuel repository on the Hanford Site (Nuclear Assurance Corporation, 1981). This study assumed that disassembly would be performed by mechanically pulling the fuel rods from their end fittings. Based on actual experience with commercial reactors, which has shown that swelling of fuel pins tends to result in 0.1 to 0.3 percent of the fuel rods in the reactor sticking in the spacers, it was conservatively assumed that 1 percent of the spent fuel rods were swollen enough to become stuck. It was further assumed that 50 percent of the stuck fuel rods were ruptured during disassembly. This failure rate is also conservative, because the equipment would be designed to release the fuel rod before it is damaged.

Failed fuel rods would be expected to release 30 percent of their gaseous fission product inventory, primarily in the form of krypton-85. This source term is consistent with guidance from the U.S. Nuclear Regulatory Commission on evaluating fuel-handling accidents at nuclear power reactors (NRC, 1972). Assuming that a repository would be designed to receive and disassemble 26 10-year-old spent fuel assemblies per day, 250 days per year (3,000 metric tons (3,300 tons) of heavy metal per year), and that krypton-85 activity is released at ground level over an 8-hour period each operating day, maximum dose to an individual residing at the Hanford Site boundary 24 kilometers (16 miles) from the repository would be 0.001 millirem per year. (Since this dose is primarily from krypton-85, a noble gas that does not accumulate in the environment or in the body, all of the dose is received in the year of release.) This whole-body dose is small in comparison to the U.S. Environmental

Protection Agency standard for exposure to the public of 25 millirems per year (EPA, 1985). The assumptions used in the estimation of radiological dose to the public from routine preclosure repository operations follow:

- The krypton-85 in 10-year-old spent fuel was 5.0×10^3 curies per metric ton of heavy metal.
- There was approximately 0.46 metric ton (0.42 ton) of heavy metal per assembly.
- The release fraction for krypton-85 was 0.30.
- The failed fuel rod fraction was 0.005.
- There were 26 assemblies per day and 250 operating days per year.
- There was a 50-year dose commitment of 4.9×10^{-4} (rem)(cubic meter)/(curie)(second).
- The annual average atmospheric dispersion factor for a ground-level release was 1.3×10^{-7} second per cubic meter at 24 kilometers (16 miles) for the repository facilities (Napier, 1981).

6.4.1.4.3 Abnormal or accident conditions

Abnormal operating or accident conditions leading to potential radiation exposure to personnel have been identified as follows (Rockwell, 1984b):

- An undetected contaminated cask, container, or vehicle in the waste-handling area.
- Exposure to unsealed hot cell ports.
- Exposure to unshielded waste containers.
- Exposure to breached casks and drums.

Abnormal operating or accident conditions that could lead to a release of radionuclides to the atmosphere and, thus, exposure to offsite personnel have been identified as follows:

- Fuel assembly drop incidents.
- Natural phenomena.
- Explosion and fire.

6.4.1.4.4 Estimated dose consequences from hoist cage-drop incident

Excluding several natural phenomena, fires, and explosions, few waste-handling operations in a repository possess the necessary source of energy required to breach containment of the waste forms. Disassembly of the spent fuel assemblies, incidents involving dropping of spent fuel assemblies, and hoist failure accidents during the lowering of the waste container to the repository can also cause breach of containment. Other repository operations involving potential accidents in the handling of packaged spent fuel in steel containers within a massive, shielded transfer cask are judged incapable of breaching containment of the waste package (Pepping et al., 1981). The hoist cage drop incident is expected to present the greatest potential for breaching containment of the waste package.

The conditions necessary to cause dropping of a waste container down the shaft would require improbable multiple failures of redundant safety systems designed to prevent such an accident. Such safety systems are standard practice in the mining industry, accounting for the low failure rate of mine hoisting systems (Rockwell, 1984b). However, irrespective of the probability of such an incident, the above accident produces sufficiently severe radiological consequences for the purposes of an environmental assessment. All other types of accidents should be smaller risk contributors than the consequences of this event.

Waste containers would be lowered to the repository level within a shielded, 27-metric-ton (30-ton) transfer cask. Breaches of the transfer cask, waste container, and spent fuel cladding are required to initiate a release. Any airborne material would be entrained in the ventilation stream and transported upward through the waste shaft, exiting through a high-efficiency particulate air filtration system in the waste-handling facility. If the transfer cask and waste container were to free fall from the shaft collar to the repository level (approximately 1,000 meters (3,300 feet)), the transfer cask would be traveling at 140 meters (460 feet) per second (Rockwell, 1984b). Although aerodynamic drag and frictional forces exerted by the cage guides and hoist ropes would reduce the impact velocity to some fraction of the free-fall velocity, the impact velocity would likely remain high enough to breach the transfer cask and container. Evaluation of potential radiation doses from such an incident would require an estimate of the quantity of radionuclide released and atmospheric disperison between the source and the receptor location. A detailed listing of the source term and assumptions used for calculating doses from a hoist cage-drop accident are presented in the generic environmental impact statement for commercial waste management (DOE, 1980, p. 5.66).

To account for expected conditions at the reference repository location, the assumptions in the generic environmental impact statement (DOE, 1980) related to atmospheric dispersion were modified for calculations used in this environmental assessment. These modifications included use of ground-level release from a repository and a distance of 1.6 kilometers (1 mile) to the maximum exposed individual located on Route 240 versus release from a 100-meter (328-foot) stack and a distance of 1.6 kilometers (1 mile) used in the generic environmental impact statement. Other assumptions remained the same (e.g., the quantity of radionuclides released and a 1-hour release period). In addition, the same type of filtration system was assumed (i.e., a roughing filter and two high-efficiency particulate air filters in series) having a total decontamination factor of 10^7. Thus, the atmospheric dispersion factor for the reference repository location was 4.0×10^{-4} second per cubic meter (1.1×10^{-5} second per cubic foot) (McCormack et al., 1984) versus 1.3×10^{-5} second per cubic meter (3.7×10^{-7} second per cubic foot) in the generic environmental impact statement (DOE, 1980). On this basis, the estimated 70-year whole-body dose commitment for the hoist cage-drop accident is 1.2 millirems for a person exposed on Route 240, 1.6 kilometers (1 mile) southwest of the reference repository location. While there is considerable uncertainty in this calculated exposure, it is believed to incorporate sufficiently the consequences of accident events resulting from malfunctions of the waste-handling system.

Natural phenomena effects (e.g., earthquakes, tornadoes, and high winds) are of concern primarily as common cause failure mechanisms that could initiate multiple failures. Design criteria for critical facilities and systems that are important to safety (e.g., high-efficiency particulate air filtration system) include consideration of these severe phenomena. The potential for a methane gas explosion is discussed in Subsection 6.3.3.2. Combustibles and explosives used in the mining operation would be controlled in accordance with applicable Federal regulations. These preliminary analyses indicate that preclosure hazards will not vary significantly from similar types of large mining and (or) construction projects ongoing in the United States.

6.4.2 POSTCLOSURE SYSTEM GUIDELINE ANALYSIS: A PRELIMINARY SYSTEM PERFORMANCE ASSESSMENT

An evaluation of long-term repository performance is required for nomination of a proposed repository site (DOE, 1984a). As specified by federal regulations (EPA, 1985; NRC, 1985a), a performance assessment for a proposed repository site requires that a probabilistic risk assessment be used to evaluate compliance with the U.S. Environmental Protection Agency standard. This risk assessment consists of an analysis of the three major repository subsystems: Waste package, repository seals, and site. The probabilistic risk assessment considers uncertainties in (1) field and laboratory data, (2) theoretical completeness of the predictive models, and (3) predictions of future conditions. The principal result of the risk assessment is a curve (Ornstein et al., 1983, pp. 313 through 319; Ortiz and Wahi, 1983, pp. 1 through 16), depicting the relationship between possible radionuclide releases (consequences) and the probability of occurrence (likelihood) of those releases. The importance of the risk curve is that it can be compared to the U.S. Environmental Protection Agency standard for radionuclide releases to the accessible environment.

This section presents a preliminary performance assessment for each of the three major repository subsystems. The performance assessment is based on a probabilistic approach that can account for data uncertainty.

Because data are not, for the most part, sufficient to permit calculation of a probability distribution, distributions were assigned subjectively based on expert judgment. The data base used is derived from available literature, field and laboratory measurements, conservative assumptions and expert judgment, and conceptual models that reflect an understanding of the geohydrological and geochemical characteristics of basalts deep beneath the Hanford Site. The results of the individual subsystem performance analyses are then combined to provide an estimate of postclosure performance for the total isolation system.

The scientific studies conducted at the Hanford Site over the past several years have yielded much data and understanding of the potential isolation performance of the reference repository location. However, definitive predictions of postclosure performance will require a more comprehensive data base and broader understanding of the geohydrologic system that would be available after site characterization. This preliminary performance assessment, together with other scientific evidence, provides a technical basis on which an evaluation can be made concerning the merit of characterizing the basalts beneath the Hanford Site. Moreover, the results of performance assessment provide insight to the identification, ranking, and prioritization of data needs for the reference repository location and vicinity.

It is important to emphasize that the following performance assessment was conducted using a preliminary data base for the reference repository location and region. Where specific information was lacking, assumptions were made based on expert judgment. This approach of using a combination of known and judgmental data values for model input is in accordance with the site-nomination and -recommendation process as stated in Section 960.3-1-4-2 of the General Siting Guidelines (DOE, 1984a). The numerical results presented in this environmental assessment are not intended to demonstrate compliance with the postclosure system guideline or the regulatory criteria and standards and are not final statements on the isolation capability of a repository in basalt. Rather, the assessment is intended to (1) demonstrate the probabilistic assessment methodology and (2) provide a quantitative basis for the preliminary findings regarding potential long-term performance. The scope of the performance assessment presented herein was defined by the U.S. Department of Energy (DOE, 1984c).

This section of the environmental assessment is organized into nine subsections: (1) Scope and objectives, (2) a description of the subsystems, (3) methodology for assessment of subsystem performance, (4) waste package performance, (5) repository seals performance, (6) site performance, (7) summary of performance assessment results, (8) a discussion of human intrusion and disruptive events, and (9) conclusions drawn from preliminary performance assessments.

6.4.2.1 Scope and objectives

The scope of this preliminary postclosure performance assessment is limited to evaluating isolation performance of the undisturbed system, (i.e., without consideration of disruptive events). Unless otherwise specified, geohydrologic conditions are assumed to be the same as before construction of a repository. Preliminary predictions of long-term performance are presented for two cases: (1) A reference case and (2) a performance limits case. The performance analysis for the reference case is conservatively based on data and assumptions that either reflect expected conditions and behavior or depict conditions under which full credit for a component or subsystem is not taken. For example, credit is not taken for the travel time through the flow interior of the Cohassett flow and for spent fuel cladding. In contrast, the analysis for the performance limits case is based on data and assumptions that specify minimal isolation performance (an even more conservative assumption) by the engineered barriers (waste package and repository seals). This case assumes that all waste is fully exposed to ground water at 300 years after closure and all radionuclides are released from the waste package at the maximum rates specified in 10 CFR 60.113 (NRC, 1985a). Potential human intrusion and plausible disruptive events, conditions, and processes are also briefly examined.

Preliminary performance assessments are presented for the individual repository subsystems and the total isolation system. As a first step, a probabilistic analysis of the performance of the subsystems for the first 10,000 years was conducted and is summarized here. The performance measures for the subsystems are as follows:

- Waste package containment time.
- Radionuclide release rates from the waste package.
- Ground-water travel time through the site.

The performance measures for the isolation system are as follows:

- Dose limits to individuals for the first 1,000 years.
- Radionuclide contamination limits in ground water for the first 1,000 years.
- Cumulative radionuclide release to the accessible environment in the first 10,000 years.

A probabilistic approach was used to estimate the ranges of uncertainties in the prediction of isolation performance. Such information is usually not attainable by classical deterministic modeling that predicts only single values.

Predictions for the performance measures were compared to applicable numerical performance objectives and standards to assess the likelihood that major repository subsystems would comply with 10 CFR 60 (NRC, 1985a) and the General Siting Guidelines (DOE, 1984a), and that the system would comply with 40 CFR 191 (EPA, 1985) for allowable releases to the accessible environment in the 10,000-year period after repository closure. Specific analyses of individual doses and radionuclide concentrations were not conducted because the performance requirements will be met by designing the waste container to last at least 1,000 years. To provide additional insight into longer term performance, a separate analysis of the entire isolation system was conducted that considered the first 100,000 years after repository closure. System performance for these cases is quantified in terms of potential radionuclide releases to the accessible environment.

6.4.2.2 Mined geologic repository subsystem descriptions

The repository isolation system consists of engineered and natural barriers to radionuclide migration. From a systems analysis standpoint, it is useful to represent these barriers as three major subsystems: Waste package, repository seals, and site. In this subsection, the nature and function of each subsystem and its components are briefly described. Subsequent subsections present the conceptual representations, describe the important processes, list the data bases used in assessing subsystem performance, and, subsequently, the performance of the isolation system.

6.4.2.2.1 Waste package subsystem description

As defined by the U.S. Nuclear Regulatory Commission (NRC, 1985a), the term waste package includes the waste form and any containers, shielding, packing, and other adsorbent materials immediately surrounding an individual waste container. The waste package is required to provide substantially complete containment of the nuclear waste for at least 300 to 1,000 years after repository closure. The current waste package design (see Section 5.1.4 and Subsection 6.4.2.3.3) for the proposed repository consists of three major components: Waste form, container, and packing.

The U.S. Department of Energy strategy currently focuses on the disposal of spent nuclear fuel (DOE, 1984b); thus, the waste packages would be designed to contain spent fuel from either pressurized water reactors or boiling water reactors. The waste form would consist of spent fuel assemblies or individual fuel rods consolidated into a more tightly packed arrangement. A typical spent fuel rod is approximately 3.7 meters (12 feet) long and is encased in a zirconium-based metal (zircaloy) tube. The metal tube is termed cladding and is highly resistant to corrosion. The nuclear fuel inside the tube typically consists of compressed and sintered cylindrical pellets of uranium oxide. Other waste forms (e.g., borosilicate glass or ceramics containing wastes from fuel reprocessing) eventually may be placed in the repository.

The spent fuel waste form would be sealed within a carbon steel container (see Section 5.1.5). The postclosure function of the container is to act as an impermeable barrier that prevents waste form and ground water contact. Based on current information, the amount of corrosion of containers in an air and steam environment during the initial 50 years after emplacement is anticipated to be minor (Anderson, 1983). Corrosion of the container is likely to affect container lifetime after permanent closure of the repository when the packing placed around the container becomes saturated with ground water. The rate at which corrosion proceeds is determined by the thermal, radiological, and chemical environment at the surface of the container. The thickness of the container would be selected to (1) compensate for corrosion, (2) withstand the in-place stresses, and (3) minimize radiolysis effects on container life.

The main function of the packing surrounding the container is to control radionuclide release rates to the host rock after closure and resaturation by (1) limiting the rate of ground-water flow past the container and (2) maintaining reducing (i.e., low Eh) conditions in which many radionuclides have low solubility. A low-permeability high-specific surface-area medium with strong adsorption properties is used to minimize radionuclide migration through the packing. Radionuclide release rates are controlled by radionuclide solubility and by adsorption in the packing material and host rock. The proposed packing material is a tailored mixture of 25 weight percent sodium bentonite and 75 weight percent crushed basalt. Because of the low ground-water flow rate projected around the waste package, the principal radionuclide-transport mechanism through the packing material should be molecular diffusion (Baca et al., 1984a; Relyea and Wood, 1984).

6.4.2.2.2 Repository seals subsystem description

The repository seals subsystem consists of backfill materials and barriers placed in the underground openings beyond the boundary of the waste package subsystem. Materials placed in boreholes drilled from the ground surface within the controlled zone are also included as components of this subsystem. The primary components of the repository seals subsystem are the shaft seals, since the shafts provide a direct connection between the underground facility and the accessible environment. Backfill placed in the underground facility to restrict ground-water flow between the waste-emplacement areas and the shafts, and thus to minimize the proportion of contaminated ground-water flow through the shafts, also is a component of the repository seals subsystem.

Backfill material placed in portions of the underground facility would be designed to inhibit ground-water flow toward the repository shafts. In addition, backfill material may provide structural support to underground openings in some areas of the repository, or may be provided to act as a sink for sorption of radionuclides in the waste-emplacement areas. Backfill also would be placed in the vertical access shafts, as well as in boreholes drilled from the surface to within the basalt flows at repository depth. Crushed basalt mixed with bentonite is currently proposed as a major component of backfill provided to inhibit ground-water flow. The composition and physical characteristics of backfill material to be used in repository seals would be further analyzed during advanced conceptual design.

Drifts provide access for personnel, materials, utilities, and ventilation during repository development and operation. The drifts that provide access to waste-emplacement boreholes in which waste packages would be emplaced are called emplacement rooms. Backfill, consisting of crushed basalt, may be placed in these emplacement rooms to provide a relatively porous sink for sorption of radionuclides released from the waste package. Access and ventilation drifts that connect the emplacement rooms to the repository shafts will be backfilled with a low-permeability crushed basalt and bentonite mixture, to the extent necessary to limit the proportion of contaminated ground-water flow entering the shafts. Injection grouting, an available technology, may be used to seal fractures that exist in the exposed rock (Rockwell, 1983b).

In shafts and boreholes drilled from the surface, low-permeability materials other than backfill may be provided as redundant barriers to ground-water flow. Concrete, metals, and vitrified basalt are being considered for such barriers. Where seals are placed in shafts, shaft liners and grout would be removed from areas of intact rock prior to seal emplacement. Detailed methods for sealing would be developed in conjunction with the upgraded conceptual and preliminary design activities.

6.4.2.2.3 Site subsystem description

The site subsystem is that natural geologic barrier that extends from the boundaries of the waste package and repository seals subsystem to the accessible environment. The site subsystem consists of the emplacement horizon (i.e., interior of the Cohassett flow in which the waste containers are emplaced), Cohassett flow top, and sequence of dense basalt, interbedded sediments, and flow tops along the predominant ground-water flow path(s) to the accessible environment.

After closure of the repository, potential radionuclide-transport paths from the emplacement horizon to the accessible environment must cross two distinct hydrologic zones. The first zone would be the thermally affected area around the repository. In this zone, ground-water flow paths and travel times would be controlled by a combination of natural hydraulic gradients and buoyancy forces induced by heat generated from the waste (Baca et al., 1981). This thermally influenced zone may extend several hundred meters (feet) vertically and horizontally from the edge of the repository. Ground-water flow in the second hydrologic zone, beyond the thermally affected zone, should be driven only by the natural hydraulic gradients.

Potential radionuclide release to the accessible environment during the time of interest (i.e., a 10,000-year period after closure) would be a function of the release rate from the waste package and the rate of radionuclide migration through the site to the accessible environment. The emplacement horizon is expected to contribute to the isolation performance of the overall repository system. The dominant mechanism that could potentially transport radionuclides from the waste package to the accessible environment is ground-water flow through the basalts and along flow tops and interbeds. For radionuclides adsorbed by minerals in the projected flow path, the effective transport velocities would be slower than the ground-water velocity. As a result, most radionuclide travel times to the accessible environment would be longer than ground-water travel times.

Ground-water travel time through the flow interior would vary, because of the anisotropy of rock transport-path properties. Local changes in site subsystem hydraulic properties during the period of peak thermal output from emplaced waste may arise from thermal-induced stresses around the underground facility. The heat may also affect site subsystem performance by changing (increasing or decreasing) the hydraulic conductivity of fractures in the rock. Geochemical properties (e.g., host rock alteration rates and radionuclide adsorption) could also change because of the effect of elevated temperature on ground-water hydrochemistry and waste and host rock interaction.

The flow top of the Cohassett flow is a likely lateral ground-water flow path, because of the existence of (1) an upward hydraulic head gradient (natural and thermal induced) across the horizon, (2) expected low vertical conductivity of the flow interior above the flow top, and (3) greater hydraulic conductivity of the flow top relative to its flow interior. Other alternative conceptual models (Gephart et al., 1983) of ground-water flow were considered (Subsection 6.4.2.6.1). Additional description of these conceptual models is given in Subsection 3.3.2.2.

The remainder of the geologic barrier of the site subsystem consists of basalt flow interiors, interbedded sediments, and relatively porous flow tops above and below the Cohassett flow. Sources of data uncertainties are similar to those of the Cohassett flow, but are likely to be of decreasing significance to performance predictions at increasing distance from the Cohassett flow.

6.4.2.3 Subsystem performance assessment methodology

Ideally, the individual subsystems of a repository should provide a diverse series of barriers to radionuclide migration (i.e., a multiple-barrier system providing defense in depth (White et al., 1981)). This multiple-barrier approach is intended to provide reasonable assurance that the total isolation system would comply with the U.S. Environmental Protection Agency standard (EPA, 1985). The strategy adopted by the U.S. Department of Energy for characterizing the reference repository location and designing a repository is based on an approach in which each repository subsystem at its boundary is required to achieve a high probability of compliance with the U.S. Environmental Protection Agency standard. This approach assures that the combined performance of the subsystems yields a higher probability (i.e., confidence) that the total isolation system would meet the U.S. Environmental Protection Agency standard. The basic approach is the subsystem performance allocation process.

In this subsection, preliminary performance assessments are presented for each of the major subsystems: Waste package, repository seals, and site. The assessments were conducted using a stochastic analysis methodology (i.e., a statistical approach to the analysis of random variables) that accounted for uncertainties in input data and provided probabilistic predictions for the important performance measures. The preliminary performance assessments for each subsystem were conducted for a 10,000-year period after repository closure.

A number of conservative assumptions were factored into the waste package, repository seals, and site subsystems performance analyses. These assumptions were included because of (1) the existing uncertainty in subsystem data bases and performance and (2) the conservative philosophy described in the General Siting Guidelines (DOE, 1984a, p. 47756), which requires evaluation of qualifying conditions to use assumptions that are ". . . realistic but conservative enough to underestimate the potential for a site to meet the qualifying condition of a guideline; that is, the use of such assumptions should not lead to an exaggeration of the ability of a site to meet the qualifying condition." The assumptions listed below either lead to (1) an underestimation of container lifetime, (2) an overestimation of the amount and (or) rate of radionuclide release from the engineered barrier system, and (3) an underestimation of ground-water travel time. As further studies are conducted and applicable data become available, the following assumptions could be modified to reflect more realistic conditions.

- Waste package subsystem

  - Container lifetime was defined as the time required to deplete 7.5 centimeters (3 inches) of container wall, not the actual designed 8.3-centimeter (3.3-inch) thickness of the container wall. This amount of depletion would reduce the container wall thickness to that which corresponds to the minimum yield strength of the container material. The container is assumed to breach when plastic yielding occurs, determined by corrosion-induced wall thinning. No credit is taken for accommodation of external pressure by plastic straining without breach or for support of the container wall by its contents (internals, waste form, and (or) canister).

  - Credit was not taken for the reduced corrosion rate that would occur with time due to the limited oxygen availability.

  - Credit was not taken for the protective effect of previously developed corrosion films on subsequent corrosion. Steels undergoing aqueous corrosion typically do not reach an equilibrium corrosion rate until several years of corrosion have elapsed. As equilibrium is approached, rates become slower in comparison to intital rates. Thus, the usage of short-term (approximately 1 year) data in the container lifetime equation is conservative, although it does assume no change in corrosion mechanisms by with time. This effect is expected to be confirmed by long-term experiments in a simulated repository environment.

- Container was assumed to disintegrate completely and thereafter not contribute to the control of radionuclide releases.
- Credit was not taken for the containment time and control of radionuclide releases provided by the spent fuel cladding.
- Credit was not taken for the time required for dissolution of the uranium dioxide matrix comprising the waste form.

- Repository seals subsystem
  - Analysis assumed all radionuclides released to the repository seals subsystem travel through the damaged rock zone and bypass the engineered barriers in the subsystem.
  - Credit was not taken for matrix diffusion.
- Site subsystem
  - Credit was not taken for the effects of matrix diffusion on radionuclide transport.
  - Credit was not taken for the process of isotopic exchange between carbon-14 and carbon-12 in the ground water.

If the above conservative assumptions were not used, predicted releases from the total isolation system would be reduced compared to releases given in Subsection 6.4.2.6.2.

6.4.2.3.1 Methods of analysis

Stochastic analysis provides a means of explicitly relating confidence (or uncertainty) levels in model predictions to uncertainties in input data. Data uncertainties can arise from (1) limitations on the number and distribution of laboratory or field measurements and (2) incomplete understanding of complex physical or chemical interactions. Stochastic modeling can incorporate such uncertainties into the analytical process. The objective of stochastic analysis is to calculate the distributions of predicted outcomes that are presented as probability curves for comparison with regulatory performance objectives. Generally, the means and standard deviations of the probability curves are of primary interest for evaluating performance compliance. The mean value of a probability curve is the average (or expected) value and generally corresponds to the centroid of the curve. The standard deviation is a measure of the spread (or dispersion) of values about the mean value. The probability curves and their statistical parameters are generated using a Monte Carlo sampling method.

A Monte Carlo method is a repetitive simulation process in which data inputs to a model are randomly selected. This method is used for translating data uncertainties to predicted uncertainties in model outputs. The Monte Carlo method has been used in a variety of technical fields (Spainer and Gelbard, 1969, pp. IX through XIV; Freeze, 1975; NRC, 1985a) and is accepted by the scientific community. This analytic approach requires estimation of the probability distributions for uncertain input parameters (e.g., flow-top transmissivity, effective porosity, and radionuclide solubility). The method is applied by following four steps:

1. Random sampling of parameter values according to their probability distributions and parameter correlations (as necessary).

2. Assigning the values from Step 1 to the appropriate input parameters, which are treated stochastically.

3. Simulating the ground-water flow and transport processes using a deterministic computer model.

4. Recording the values of the output performance measure.

The computational process is repeated a large number of times until the final output, a probability curve, is defined. The principal result of the stochastic simulation is cumulative or complementary-cumulative probability curves for the performance measures (i.e., ground-water travel time, radionuclide-release rate, and cumulative radionuclide release). From such curves, the probability (or confidence level) of achieving compliance with a regulatory criteria or standard can be estimated.

Various stochastic simulation models have been developed (Sonnichsen, 1984) to predict the performance of major repository subsystems: Waste package, repository seals, and site. In general, these models use the approach illustrated by Figure 6-12. In subsequent sections of this environmental assessment, the capability of the models is demonstrated with specific applications. The principal computer codes used in the preliminary performance assessment are as follows:

1. CHAINT-MC for the waste package subsystem.

2. REPSTAT for the repository seals subsystem.

3. PORMC-SF for ground-water flow in the site subsystem.

4. EPASTAT for radionuclide-transport simulations of the site subsystem.

Formal documentation in accordance with the U.S. Nuclear Regulatory Commission guidelines (Silling, 1983) for these computer codes has not been issued, since the codes are still undergoing development. These codes have been verified with analytical solutions and (or) benchmarked with other codes; however, this code testing is not yet completed and documented.

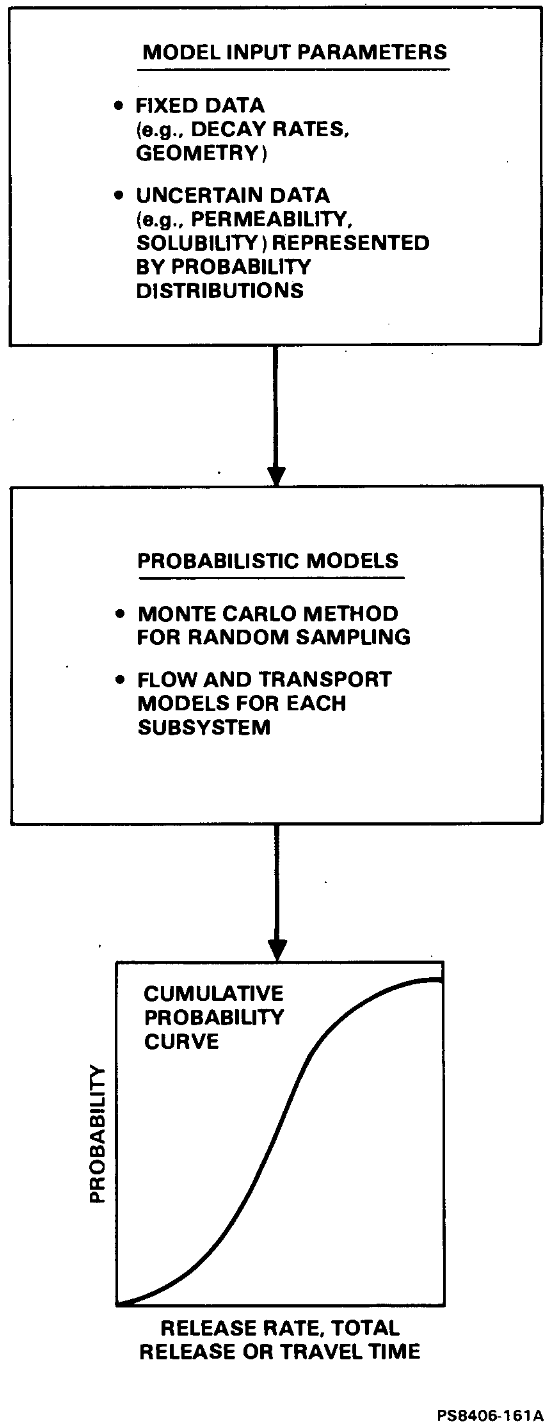


Figure 6-12. Stochastic approach for parameters applied to subsystem performance assessment.

6.4.2.3.2 Identification of radionuclides used in performance assessment

The spent fuel waste form contains more than 100 different radionuclides. Many of these radionuclides are not significant to long-term isolation performance due to their short half-lives, low solubilities, or high adsorption. Thus, only a relatively small number of radionuclides need to be considered in assessing isolation performance. For purposes of this report, these radionuclides are defined as radionuclides that, if released from the waste package in significant quantities relative to the U.S. Environmental Protection Agency release limits (EPA, 1985), could potentially reach the accessible environment within 10,000 years. For the purpose of screening radionuclides as discussed in this document, the U.S. Environmental Protection Agency criteria have been considered to be the overriding safety criteria. A similar screening procedure with respect to the U.S. Nuclear Regulatory Commission release-rate criterion (NRC, 1985a) could be devised in the future. Properties of radionuclides that facilitate transport to the accessible environment include long half-lives, large inventories, high solubility, and low adsorption. As data become available, future analyses to identify significant radionuclides will also consider colloid and particulate transport of radionuclides and ground-water transport of chemically complexed species. The radionuclides important for assessing repository performance were identified for the spent fuel waste form using a four-step selection procedure. The screening procedure was based on the following assumptions.

1. Isolation period of concern is the first 10,000 years after repository closure.

2. Emplaced waste form is 10-year-old spent commercial reactor fuel.

3. Water resaturates the repository immediately after closure.

4. Complete disintegration of fuel cladding and container occurs after approximately a 5,000-year containment period (Subsection 6.4.2.3.3 discusses container lifetime estimates).

5. Instantaneous dissolution of all waste form matrix occurs after the containment period.

The radionuclide-transport calculations for selecting the significant radionuclides were conducted using a simplified model that simulates radionuclide release as a function of the processes of molecular diffusion, decay, and adsorption. At each step of the procedure, radionuclides were eliminated from further consideration, based on criteria described in the following paragraphs.

Step 1—Initial inventory

In the first step of the screening procedure, the inventory fraction (i.e., the ratio of maximum radionuclide inventory during the first 10,000 years to the applicable U.S. Environmental Protection Agency release limit (EPA, 1985)) was computed for each radionuclide and then compared to the 1.0 percent inventory criterion. This criterion was selected because radionuclides with inventory fractions of less than 1.0 percent are unlikely to contribute significantly to the total release, irrespective of their rates of release or rates of migration. The inventory fractions were calculated using radioisotope inventories reported by the U.S. Department of Energy (DOE, 1979). The maximum radionuclide inventories were used to account for the formation of daughter-product radionuclides. Radionuclides with inventory fractions of 1.0 percent or less were eliminated from further consideration.

Step 2—Half-life

The waste packages for a repository in basalt are expected to be designed to contain the radioactive wastes for durations in excess of 1,000 years. During this containment period, many radionuclides with short half-lives will decay to insignificant levels. A time equivalent to 50 half-lives is more than sufficient to reduce the inventory of any radionuclide to an acceptably small fraction. For example, a radionuclide with a half-life of 100 years (or less) would decay to 10^{-13} percent (or less) of its initial inventory in 5,000 years. Therefore, radionuclides (not eliminated in Step 1) with half-lives of 100 years or less were eliminated from further consideration.

Step 3—Solubility

According to conservative estimates (Salter and Jacobs, 1983; Early et al., 1982) and preliminary laboratory data, several radionuclides in the waste form have relatively low solubilities. The term solubility, as used here, is defined as the steady-state concentration (resulting from dissolution and precipitation) that limits the rate at which a radionuclide dissolves in the ground water. In general, low solubility together with diffusion-controlled mass transport can usually limit radionuclide releases to insignificant amounts. As in the previous step, an insignificant amount is defined as a release fraction (i.e., calculated cumulative release from the waste package normalized to the U.S. Environmental Protection Agency release limit (EPA, 1985)) that is less than or equal to 1.0 percent. Performance was assessed relative to this criterion by computing the cumulative release at the waste package subsystem boundary (interface between waste-emplacement borehole and the packing) for each radionuclide and then comparing the fractional release to the 1.0-percent criterion. The calculations for this step were performed assuming no radionuclide adsorption (i.e., radionuclide retardation) by the waste package packing material or host rock to identify those radionuclides that are strongly solubility limited. Radionuclides with releases smaller than allowed were not considered further.

Step 4—Adsorption

Adsorption of radionuclides by the minerals along the flow path through the waste package packing is important because of its ability to retard radionuclide movement. The effects of this chemical process are manifested in terms of increased radionuclide travel times and reduced radionuclide releases. In this step of the selection procedure, a 1.0-percent cumulativerelease fraction criterion was used. Cumulative releases for each radionuclide were calculated using the transport model, but with adsorption accounted for by applying a retardation factor (Freeze and Cherry, 1979, pp. 402 through 413). Conservative values of solubility (i.e., highest current estimates) and adsorption (i.e., lowest current estimates) coefficients (Salter and Jacobs, 1983) were used. The cumulative releases for each radionuclide during 10,000 years were calculated across the waste package boundary. The resultant calculated releases were then compared to the 1.0-percent criterion. Radionuclides not exceeding the criterion were eliminated from further consideration.

After applying these four screening steps by means of the computer simulations of waste package performance, six radionuclides remained that appeared to merit priority consideration in the postclosure performance assessment for a repository in basalt. These six radionuclides are carbon-14, selenium-79, neptunium-237, iodine-129 tin-126, and technetium-99. The radionuclides of greatest significance to total system performance are probably carbon-14 and iodine-129, because of their relatively high solubilities, nonadsorptive properties, and relatively long half-lives. The degree to which radiocarbon exchanges with natural carbonate along the flow path is unknown. Such exchanges may have significant effects on limiting the rate of release from the waste package.

In analyses of subsystem performance, transport calculations were also performed for three isotopes of plutonium (plutonium-239, -240, and -242) in addition to the six radionuclides noted above (DOE, 1984c). Analysis of plutonium was added, since the original screening process neglected releases that could occur after 10,000 years. Plutonium was selected because of its relatively large inventory. Therefore, even low releases over a 100,000-year time period could be significant. In addition to plutonium, americium-241 and radium-226, which are often perceived to be significant radionuclides because of high inventories of their parents, were added to the list. Thus, in all, eleven radionuclides were analyzed in detail.

Although the screening process focused on cumulative release as the criterion for judging whether a radionuclide warranted further consideration, the solubility, half-life, and inventory of cesium-135 suggested that it might possibly have a high release rate and should, therefore, be analyzed to assess compliance with the U.S. Nuclear Regulatory Commission release-rate criterion (NRC, 1985a). Consequently, a release-rate analysis was conducted that revealed a peak fractional release rate of 6×10^{-8} per year. This is approximately three orders of magnitude below the allowable limit; a result dominated by strong sorption in the waste package packing material. No further consideration of cesium-135 was deemed necessary.

6.4.2.4 Waste package subsystem performance

The basic function of the waste package subsystem is to provide engineered barriers in addition to the dominant barrier of the site subsystem. The U.S. Nuclear Regulatory Commission performance objectives (NRC, 1985a) for performance of the engineered barriers require that (1) waste packages provide substantially complete containment of the spent fuel for 300 to 1,000 years and (2) radionuclide-release rate (after a 1,000-year containment) not exceed one part in 100,000 per year at the engineered barrier system boundary. The release-rate requirement was assumed to apply at the waste package boundary, which lies within the engineered barrier boundary. This requirement does not apply to any radionuclide that is released at a rate less than 0.1 percent of the calculated total release-rate limit. The U.S. Nuclear Regulatory Commission criteria (NRC, 1985a) provide for the specification of alternative numerical limits for waste package subsystem release rates, provided that there is reasonable assurance that the total system will achieve compliance with the U.S. Environmental Protection Agency standard (EPA, 1985).

Figure 6-13 illustrates the allowable release rate for typical spent fuel. The solid line of the figure consists of a horizontal segment representing the minimum required release rate (0.1 percent x total release-rate limit) and a 45-degree segment representing 1×10^{-5} times the inventory. The total release-rate limit is 1×10^{-5} times total inventory, or

$$(1 \times 10^{-5}) \times (1.6 \times 10^{3}) = 1.6 \times 10^{-2} \text{ curie per metric ton of uranium per year.} \qquad (6\text{-}5)$$

The minimum required release rate is 0.001 times the total release limit, or 1.6×10^{-5} curie per metric ton of uranium per year.

For any radionuclide, the allowable fractional release rate is equal to allowable release rate divided by inventory. Along the 45-degree line segment in Figure 6-13, the value is always one part in 100,000. At inventories lower than 0.1 percent of the total inventory, however, the allowable fractional release rate is the minimum 0.1 percent of the total release-rate limit divided by the inventory. For selenium-79, the value is 1.6×10^{-5} divided by 3.5×10^{-1}, or 4.6×10^{-5}. This value is slightly less restrictive than the one part in 100,000 constraint. For iodine-129, the minimum required release rate divided by inventory is approximately 5×10^{-4}, a fairly significant departure from one part in 100,000. The U.S. Nuclear Regulatory Commission waste package release-rate performance objective, as interpreted for this report, is that a low inventory radionuclide in effect relaxes the performance objective, but does not exempt the radionuclide from regulation. In contrast, allowable release rates for radionuclides with inventories higher than 0.1 percent of the total inventory release-rate limit (e.g., technetium-99 and plutonium-240) are indicated by the 45-degree line segment of the curve shown in Figure 6-13.

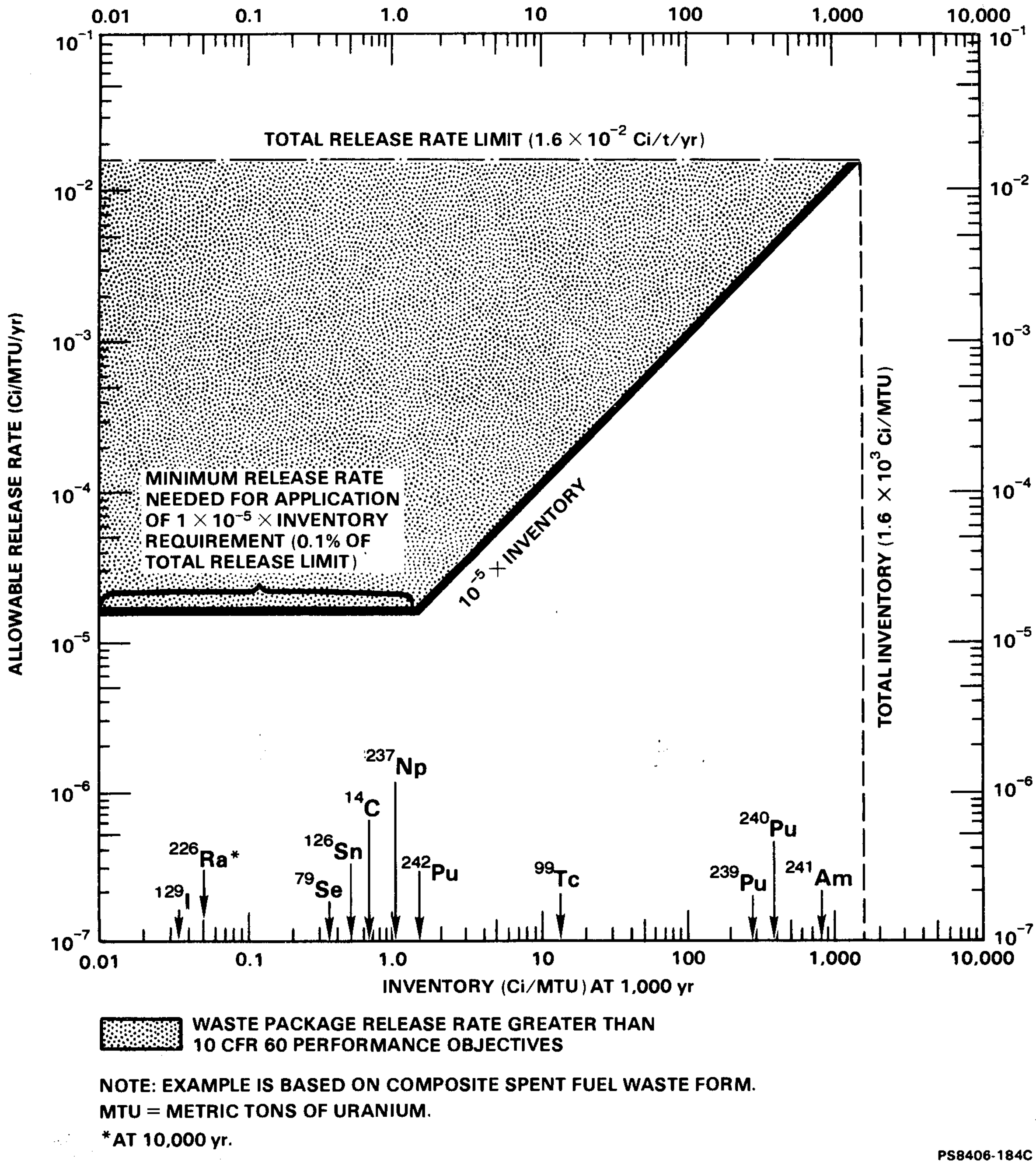


Figure 6-13. Waste package subsystem release-rate requirement of 10 CFR 60 (NRC, 1985a).

How well the current waste package design complies with the above performance objective could also affect compliance with the U.S. Environmental Protection Agency standard (EPA, 1985) for (1) the requirement for protection of major sources of ground water (Subsection 6.4.2.9.4) and (2) the limit on cumulative radionuclide release at the accessible environment boundary. For example, if performance of the waste package subsystem is such that a 1,000-year containment is achieved with high confidence, then there is reasonable assurance that the ground-water protection requirement of 40 CFR 191 (EPA, 1985) would also be met. Similarly, if performance of the waste package is such that there is high probability that the cumulative radionuclide releases (at the waste package subsystem boundary) is less than the U.S. Environmental Protection Agency limits, then there is greater assurance that the site subsystem (and, therefore, the overall system) would comply with the release limit at the accessible environment boundary.

Stochastic simulations of waste package subsystem performance were conducted to examine the likelihood of compliance of subsystem performance with the U.S. Nuclear Regulatory Commission performance objectives (NRC, 1985a), taking into account the ranges of uncertainties in the input data and parameters. The analysis of subsystem performance focuses on the first 10,000 years after closure and calculates probability curves for three performance measures: Container lifetime, fractional radionuclide-release rates, and cumulative radionuclide release at the waste package subsystem boundary.

6.4.2.4.1 Method of analysis

The calculation sequence for estimating the fractional release rate of each significant radionuclide at the boundary of the waste package subsystem consists of the following four steps:

1. The probability of a typical container failing in a given time interval is computed using an empirical corrosion model.

2. The random failure of containers is represented by a nonhomogeneous Poisson stochastic process. The parameters of this process are estimated from the probability distribution obtained in Step 1.

3. Samples of the fractional release rate versus time function for a single container failing at time zero are obtained using random sampling of radionuclide solubility and adsorption coefficients (Monte Carlo simulations).

4. The fractional releases from the large set of containers in the repository are estimated by combining the releases of Step 3 with the random failure sequence of Step 2 through the mathematical process referred to as convolution.

A summary of these steps is provided below. Full details of the calculational methods are available in Sagar et al. (1984).

6.4.2.4.2 Analysis of container corrosion

Although several container materials are being studied, the leading candidate material is low-carbon steel. Based on designed container integrity under estimated stress conditions and allowing for estimated rates of corrosion, the current container conceptual design specifies a wall thickness of 8.3 centimeters (3.3 inches). For this analysis, the container is assumed to have failed when the corrosion penetration equals 7.5 centimeters (3 inches). At such time, the waste form is assumed to be available for dissolution. The failure criterion is attainment of the material yield strength in the cylindrical container wall. As the wall thickness decreases by uniform corrosion penetration, the stress in the wall would increase until the yield stress is reached. It is recognized that a more rigorous analytical approach to take into account buckling failure, nonaxisymmetric loading, and stresses in the container ends and joints will eventually be necessary. Future waste package performance assessments will include such considerations.

The container corrosion model, details of which are provided by Fish and Anantatmula (1983), consists of a set of empirical equations that give the corrosion penetration as a function of time under air-and-steam and aqueous conditions at various temperatures. The coefficient values in the model equations are estimated from laboratory data on corrosion of low-carbon steel in a simulated repository environment. The general corrosion analysis, which only considered uniform corrosion, considers environmental conditions for three periods in the life of the container: (1) An air and steam environment (0-100 years), (2) a high-temperature (greater than 125°C (257°F)) aqueous environment (100-300 years), and (3) a lower temperature (less than 125°C (257°F)) aqueous environment beyond 300 years (Sagar et al., 1984). Additional conservative assumptions are noted in Subsection 6.4.2.3.

Because of the variation in waste age in the containers, the variation in time of container emplacement in the repository and the variation in physical conditions (temperature, rate of water saturation) that waste containers will be subjected to over their lifetimes, the corrosion rate will vary over the surface of each container and from container to container. However, in this analysis, uniform corrosion over the surface of each container was assumed. For these reasons, all containers in the repository are not expected to fail at the same time. Causal relationships between the conditions that cause varying rates of corrosion (i.e., temperature) and the resultant rate of corrosion are not specified by the current corrosion model. In this analysis, the uncertainty in the actual corrosion rate is accounted for in the empirical coefficients of the corrosion equations. The range of these coefficients is based on the range observed in the experimental data and preliminary technical judgment (Sagar et al., 1984). The data are from short-term experiments (on the order of weeks) and no explicit relationship between these coefficients and the corrosion-causing conditions has been stipulated. In addition, because the range of corrosion-causing environmental conditions in the repository is not totally understood, it cannot be asserted that the assumed range reflects the variation of corrosion rates that the containers will experience. Test programs to identify the range of repository parameters important to corrosion are ongoing. These programs include quantification of redox conditions of the waste package environment, range of groundwater compositions expected (including dissolved gases such as methane), and effects of decreasing temperature and radiation flux on the waste package. Results from these tests will be considered in future waste package analyses.

Results from corrosion analysis of a typical container are shown in Figure 6-14. These results were obtained through Monte Carlo simulation of the corrosion equations. The results in Figure 6-14 are obtained when the coefficients of the corrosion model are assumed to have a Gaussian distribution (truncated on either tail by the specified range). The probability density function and the cumulative probability distribution of container failure (the time at which corrosion penetration becomes equal to 7.5 centimeters (3 inches)) are plotted in Figure 6-14. The probability density function provides an estimate of the probability of container failures within a given time. The cumulative probability distribution curve shows probability of the container lasting a specified number of years. The probability that a typical container will fail in less than 1,000 years is estimated to be close to zero. The mean and standard deviation of container lifetime are estimated to be 6,100 and 600 years, respectively. Results for the case in which the coefficients of the corrosion equation are assigned a uniform probability distribution are discussed in Sagar et al. (1984). Because Gaussian probability distributions of corrosion parameters result in higher peak fractional release rates than those obtained by using uniform probability distributions, this relatively more conservative distribution assumption was adopted for further analyses.

Only uniform corrosion was included in the above analysis. Other possible corrosion modes have been considered, as discussed in greater detail in Subsection 6.3.1.2.8. Other corrosion modes were not found to be significant, based on literature studies and test results in simulated Hanford Site ground-water environments. Tests are ongoing for other modes of corrosion (e.g., stress-corrosion cracking and pitting). Results from these tests will be incorporated into future container corrosion models as appropriate. Testing will be conducted over the full range of expected container environmental conditions to quantify the relationship between environmental conditions and container degradation. At present, the container is expected to be exposed to oxidizing, air and steam conditions only during the operation and resaturation periods of the repository. Reducing conditions are expected during subsequent, postclosure aqueous exposure. Future investigations are intended to verify these environmental assumptions.

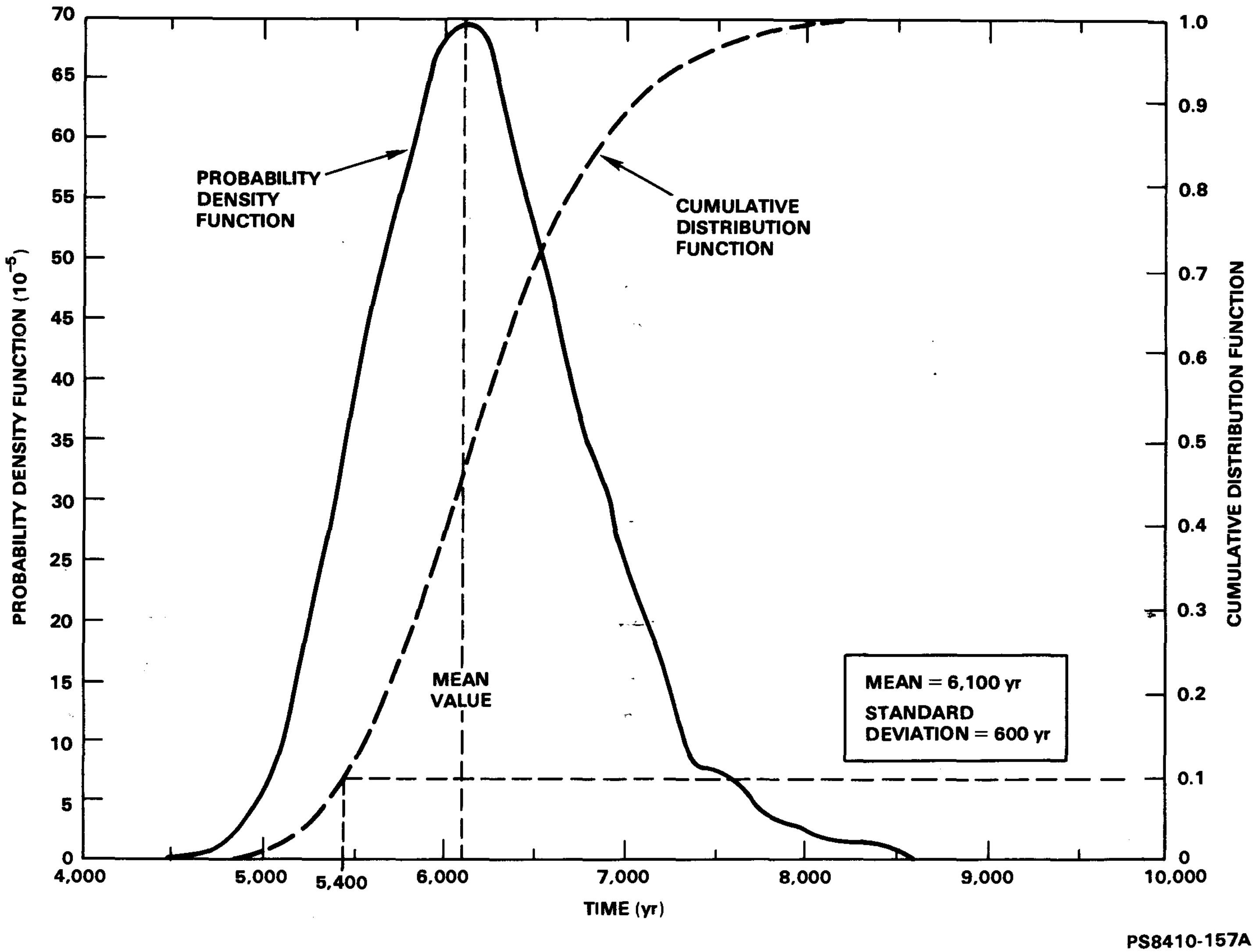


Figure 6-14. Probability curves for failure of a typical container.

6.4.2.4.3 Distribution of container failure

The current waste package design specifies a container capacity of 1.8 metric tons (2 tons) of waste. To accommodate the repository design capacity of 70,000 metric tons (77,000 tons) of heavy metal, up to approximately 40,000 containers would be emplaced in the repository. For the reasons stated in the previous subsection, all of the containers are not expected to fail simultaneously. Although it is not possible to estimate the exact corrosion rate for each container, it was assumed that the probability curves of Figure 6-14 are applicable to individual containers. This assumption implies that any of the conditions that define the probability curve of Figure 6-14 may be realized for any container. Given one further assumption, that container failures are statistically independent, a nonhomogeneous Poisson process can be used to describe the distribution of container failures. The Poisson process is a single-parameter stochastic process (Parzen, 1962), with the rate of container failures as the parameter. In the nonhomogeneous Poisson process, this parameter is a function of time and is approximately equal to the product of the number of containers in the repository and the value at any given point on the probability density curve of Figure 6-14 (Sagar et al., 1984). From Figure 6-14, it is evident that containers begin to fail at a low rate at about 4,500 years, reach a peak failure rate at 6,100 years, and all containers have failed by about 8,500 years. Approximately, 90 percent of the container failures occur during a 2,000-year interval from approximately 5,300 to 7,300 years. The peak container-failure rate is approximately 30 containers per year.

6.4.2.4.4 Estimation of release from a single container

The computer code adopted for estimating fractional release rates from a single container is CHAINT-MC (Baca et al., 1984b; Kline et al., 1986). This computer code solves the convection-dispersion equation of mass transport in two or quasi-three dimensions, using the finite-element method (Baca et al., 1984a). The code incorporates various processes that are important to radionuclide migration, (e.g., chain decay, sorption, molecular diffusion, and hydrodynamic dispersion). This model can be used for modeling releases under conditions of layering or arbitrary heterogeneity and anisotropy. The code is designed to perform Monte Carlo simulations by repeatedly solving the mass transport equation using parameter values obtained by sampling from specified probability distributions of parameters. The computer code CHAINT-MC has been verified, in a preliminary fashion, for a variety of test problems (Baca et al., 1984b).

Based on the considerations discussed in Subsection 6.4.2.3.2, 11 radionuclides (carbon-14, selenium-79, technetium-99, tin-126, iodine-129, neptunium-237, americium-241, radium-226, and plutonium-239, -240, and -242) were considered in the waste package subsystem performance analysis. The waste package subsystem analysis was conducted for the current waste package design. This design specifies that containers have a 25.2-centimeter (9.9-inch) radius, a wall thickness of 8.3 centimeters (3.3 inches), and a length of 4 meters (13 feet). The packages are emplaced in boreholes 6 meters (236 inches) in length with a radius of 44.5 centimeters (17.5 inches), and a center to center separation of 7 meters (23 feet). The 19.3-centimeter (7.6-inch) gap between the container and the borehole wall will contain a prefabricated packing. At resaturation, the packing is assumed to fill the entire gap between the container and the borehole wall. Accordingly, the waste package subsystem boundary was specified to be located 19.3 centimeters (7.6 inches) from the outer wall of the container.

It was further assumed that a portion of the host rock around the boreholes is disturbed during drilling and excavation operations. Outward from the borehole wall, a host rock thickness equal to one-fifth of the borehole radius was assumed to be damaged to the extent that its effective porosity is an order of magnitude higher than that of the intact host rock. Beyond the damaged rock zone, a rock thickness equal to one borehole radius was assumed to be disturbed to the extent that its effective porosity is approximately twice that of the undisturbed host rock. For this analysis, the borehole was conservatively assumed to be surrounded by a damaged rock zone approximately 9 centimeters (3.5 inches) thick, which in turn is enclosed by a zone of induced stress 44.5 centimeters (17.5 inches) thick. Specifications for components of the waste package are summarized in Table 6-24. The conceptual model for the waste package is shown in Figure 6-15.

Table 6-24. Data set for assessment of waste package subsystem performance

Item	Specification
Container material type	Low-carbon steel
Container length	4 m (13 ft)
Container outer radius	25.2 cm (9.9 in)
Container wall thickness	8.3 cm (3.3 in)
Container capacity (pressurized water reactor fuel)	1.8 t (approximately 2 tons) of heavy metal
Borehole radius	44.5 cm (17.5 in)
Damaged rock thickness	9 cm (3.5 in)*
Disturbed rock thickness	44.5 cm (17.5 in)*

*Assumed value.

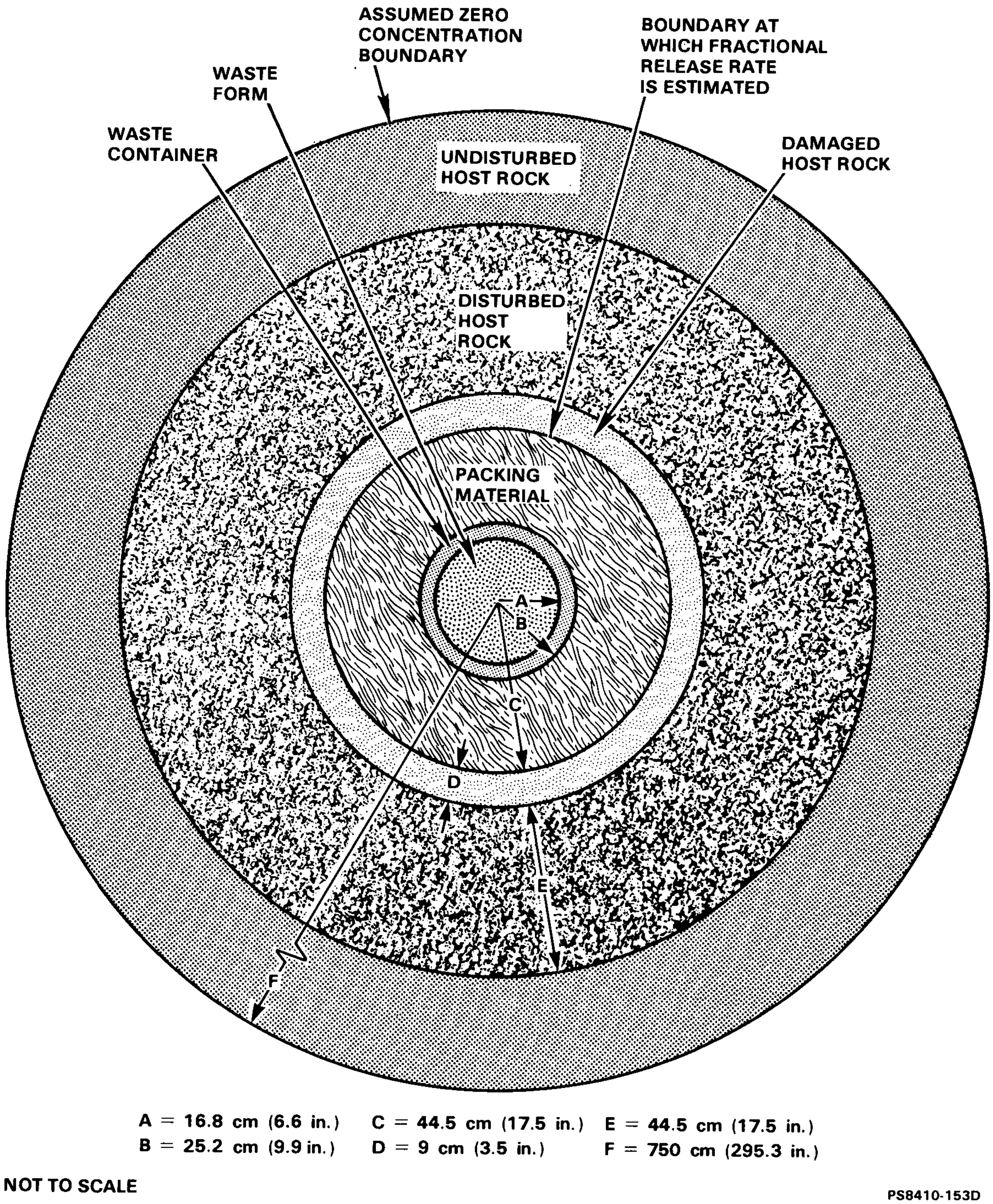


Figure 6-15. Conceptual model used in the estimation of fractional release from a single typical waste package.

Inventories of the 11 selected radionuclides at 1,000 years, their half-lives and specific activities, and ranges of solubilities and sorption coefficients are given in Table 6-25. The steady-state concentration ranges (utilized as solubilities in this analysis) reported in Table 6-25 are based on theoretical considerations (Salter and Jacobs, 1983) and include experimental values. At present, there is significant uncertainty as to the actual values of radionuclide steady-state concentrations in the repository environment. Firm inferences regarding their probability distribution are not possible from the limited amount of experimental data. However, review of available literature revealed that loguniform (Ortiz and Wahi, 1983) and lognormal distributions (NRC, 1983b) for solubilities had been used elsewhere. A parametric study (Sagar et al., 1984) indicated that a uniform probability distribution of solubility values would produce conservative results (i.e., would predict greater fractional radionuclide releases than those predicted by assuming a loguniform or lognormal distribution. The expected value and the standard deviation of the three distributions (uniform, loguniform, and lognormal) were calculated from the range specified in Table 6-25. The sorption coefficient ranges specified in Table 6-25 are for basalt, and are considered to be conservative (i.e., lower) relative to expected values for packing and flow-top material. A uniform probability distribution was assumed for sorption coefficient values. (Uses and effects of other probability distributions are discussed in Sagar et al., 1984.) Effective porosity and diffusion coefficients were deterministically assigned for purposes of this analysis and their values are reported in Table 6-26.

For the flow interior, radionuclide transport may occur through discrete features (e.g., fractures), which contain less surface area for adsorption compared to flow tops. This factor introduces uncertainty in the applicability of available adsorption data to basalt flow interiors. Hence, for the purposes of this analysis, sorption in the flow interiors was assumed to be zero.

Because of the expected low hydraulic conductivity of the packing material (approximately 10^{-12} meter per second (10^{-7} foot per day)) and because container lifetime is such that buoyancy forces are dissipated before releases begin, the advective component of radionuclide transport (e.g., radionuclide migration produced by water movement) is relatively small. Therefore, the primary mechanism for migration of the radionuclides through the packing material should be molecular diffusion (Baca et al., 1984a; Relyea and Wood, 1984). In this analysis, radionculide migration is modeled as occurring radially.

The outer boundary of the conceptual model used in assessing waste package subsystem performance is 7.5 meters (24.6 feet) from the center of the container (see Fig. 6-15), which is in the intact host rock of the Cohassett flow interior. A zero concentration of radionuclides is assumed at this boundary. In a completely two-dimensional analysis, definition of the zero-flux boundary as midway between two container locations, which is approximately 6.7 meters (22 feet), would be dictated from strict symmetry considerations. Compared to such a boundary condition, the assumption of a zero-concentration boundary at 7.5 meters (24.6 feet) (one-dimensional

Table 6-25. Radionuclide data set for assessment of waste package subsystem performance

Radionuclide	Inventory at 1,000 yr (Ci/MTU)a	Half-life (yr)	Specific activity (Ci/g)	Radionuclide solubilityb (moles/L)	Adsorption coefficient (mL/g)
Americium-241	3.50 x 103[c]	4.32×10^{2}	3.46×10^{0}	1.0×10^{-10} to 1.0×10^{-9}	68 to 170
Carbon-14	6.55 x 10-1	5.73×10^{3}	4.457	4.0×10^{-9} to 4.0×10^{-6}	0
Iodine-129	3.3 x 10-2	1.59×10^{7}	1.74×10^{-4}	1.0×10^{-2} to 1.0×10^{0}[d]	0
Neptunium-237 2 to 10	1.1 x 100	2.14×10^{6}	7.05×10^{-4}	1.0×10^{-10} to 1.0×10^{-5}	
Plutonium-239	2.82 x 102	2.41×10^{4}	$6\ 20 \times 10^{-2}$	6.0×10^{-10} to 6.0×10^{-6}	4 to 21
Plutonium-240	4.05 x 102	6.53×10^{3}	2.28×10^{-1}	3.0×10^{-10} to 9.0×10^{-6}	4 to 21
Plutonium-242	1.6 x 100	3.76×10^{5}	3.93×10^{-3}	1.0×10^{-10} to 1.0×10^{-6}	4 to 21
Radium-226	5.00 x 10-2[c]	1.60×10^{3}	1.00×10^{0}	1.0×10^{-8} to 1.0×10^{-6}	20 to 50
Selenium-79	3.46 x 10-1	6.50×10^{4}	6.96×10^{-2}	1.0×10^{-8} to 1.0×10^{-4}	0.8 to 4
Technetium-99	1.29×10^{1}	2.13×10^{5}	1.70×10^{-2}	2.0×10^{-8} to 5.0×10^{-4}	0 to 15
Tin-126	4.77 x 10-1	1.00×10^{5}	2.84×10^{-2}	3.0×10^{-11} to 3.0×10^{-6}	2 to 5

NOTE: Taken from Salter and Jacobs (1983).

[a]Taken from U.S. Department of Energy (DOE, 1979).

[b]Computed by multiplying the element solubility by the nuclide fraction.

[c]Maximum inventory during the first 10,000 years.

[d]Due to its small inventory, the release rate of iodine-129 is not controlled by solubility. A solubility higher than that specified in this table will not lead to higher fractional release rates.

analysis) results in prediction of greater releases than the two-dimensional analysis and, hence, is conservative. Note that the releases of radionuclides are estimated at the packing material and rock interface, which is the radius marked C in Figure 6-15.

Table 6-26. Transport property data set for assessment of waste package subsystem performance.

Parameter	Packing	Zone		
		Damaged host rock	Disturbed host rock	Undisturbed host rock
Effective porosity	3×10^{-1}[a]	1×10^{-3}[a]	2×10^{-4}[a]	1×10^{-4}[b] 5×10^{-3}[c]
Diffusion coefficient, cm^2/s[a] (ft^2/min)	1×10^{-5} (1×10^{-4})	1×10^{-6} (1×10^{-5})	1×10^{-6} (1×10^{-5})	1×10^{-6}[b,c] (1×10^{-5})

[a]Value assumed.
[b]Flow interior (value assumed).
[c]Flow top (value assumed).

The results from this calculational step is the fractional release rate as a function of time for each simulation. A total of 200 Monte Carlo cases was performed.

6.4.2.4.5 Estimation of fractional radionuclide release from all containers at the waste package subsystem boundary

The final step in the calculation sequence is to estimate the fractional radionuclide release resulting from probabilistically distributed failures of the entire set of waste containers in the repository. As stated previously, the container failures are stipulated to occur in the manner of a nonhomogeneous Poisson process. Thus, containers fail at random time intervals, the probabilities of which are determined by the Poisson (single-parameter stochastic) process. The fractional release rate from the entire set of containers is obtained by adding the release resulting from the random failures of individual containers. This summation process is described in detail in Sagar et al. (1984).

The key results of this analysis are presented in Figures 6-16 through 6-18. The figures show the expected values of fractional release rates at the waste package subsystem boundary as a function of time. The vertical bar at the peak fractional release rate depicts the magnitude of three standard deviations. The probability that the fractional release

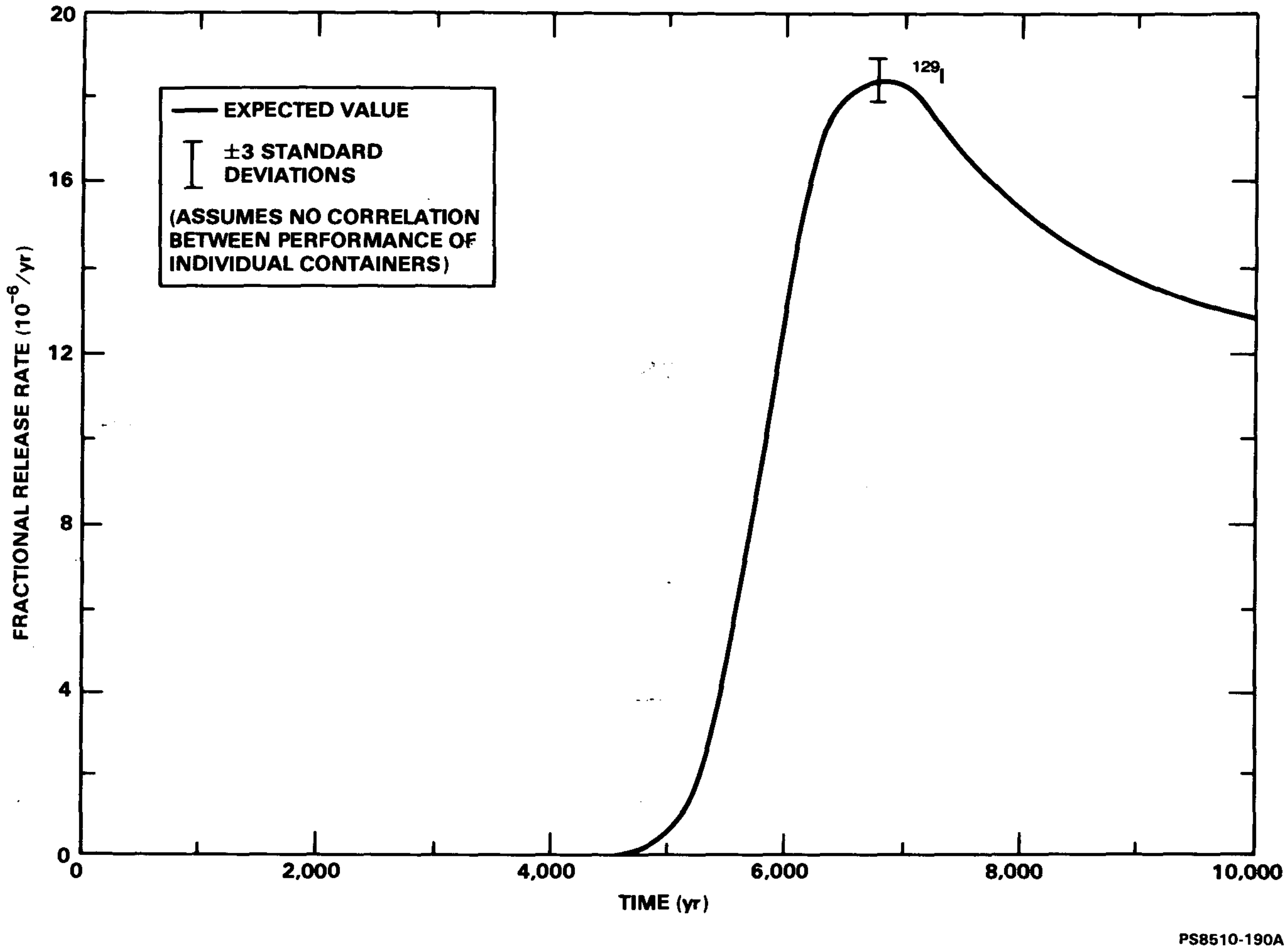


Figure 6-16. Maximum fractional radionuclide-release rates of iodine-129 at the waste package subsystem boundary.

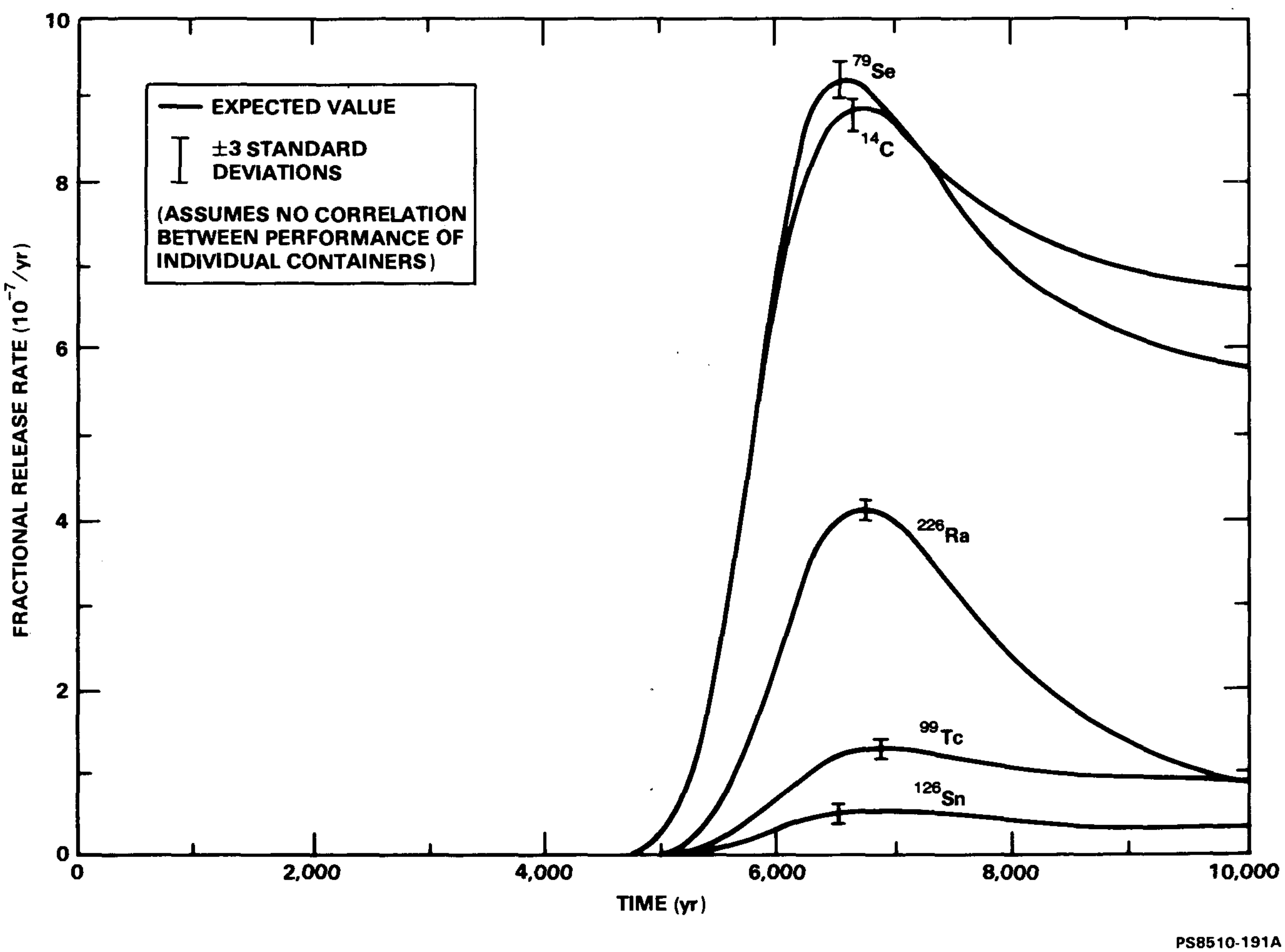


Figure 6-17. Maximum fractional radionuclide-release rates of selenium-79, carbon-14, radium-226, technetium-99, and tin-126 at the waste package subsystem boundary.

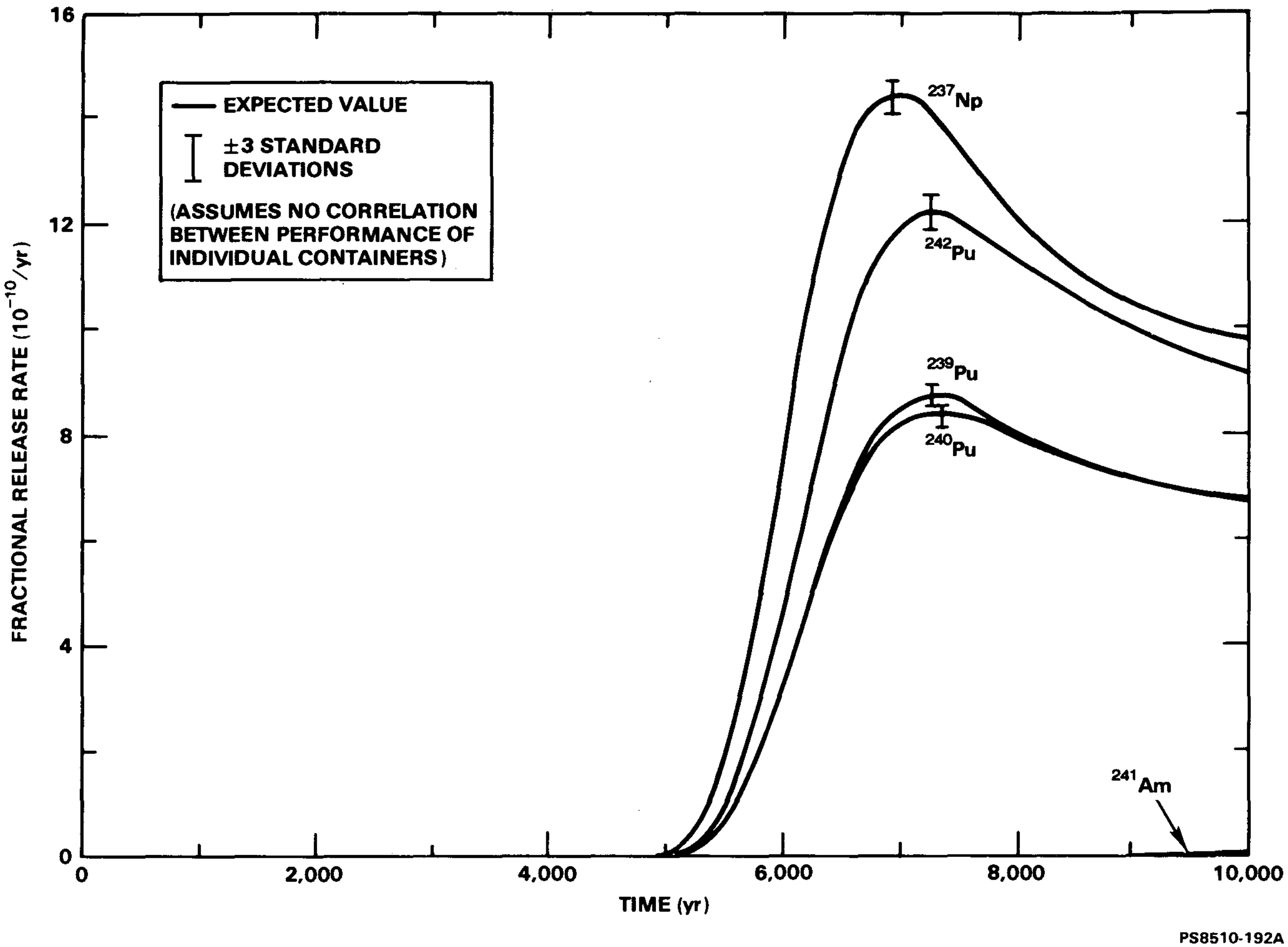


Figure 6-18. Maximum fractional radionuclide-release rates of neptunium-237, plutonium-239, -240, and -242, and americium-241 at the waste package subsystem boundary.

rate is less than the predicted value plus three standard deviations is approximately 90 percent (Benjamin and Cornell, 1970, pp. 140 through 142). The predicted value of the maximum fractional release rates plus three standard deviations are, therefore, the values that are compared with the U.S. Nuclear Regulatory Commission criterion (NRC, 1985a). The curves of Figures 6-16 through 6-18 were obtained by assuming that probabilities of radionuclide solubility values are distributed uniformly. The results, when radionuclide solubilities are assumed to have loguniform or lognormal distributions, are compared to the results from uniform distribution in Table 6-27. As expected, uniform probability distribution of solubility values result in the highest predicted peak fractional release rates. The predicted release rates for the 11 radionuclides are less than the U.S. Nuclear Regulatory Commission performance objectives (NRC, 1985a).

To determine if the waste package subsystem satisfies the subsystem performance allocation goals, the cumulative radionuclide release during 10,000 years at the waste package subsystem boundary was also estimated (Fig. 6-19 through 6-21). For convenience, the cumulative releases were calculated in terms of the U.S. Environmental Protection Agency (EPA, 1985) standard. In the standard, these limits are specified at the boundary of the accessible environment, which is approximately 5 kilometers (3 miles) beyond the waste package subsystem boundary. It is emphasized that neither the U.S. Nuclear Regulatory Commission nor the U.S. Environmental Protection Agency have specified cumulative release limits for the waste package subsystem boundary. Therefore, the purpose of performing this calculation was to estimate the contribution that the waste package provides toward meeting the U.S. Nuclear Regulatory Commission and the U.S. Environmental Protection Agency limits and to judge the degree of redundancy to other repository subsystems that is provided by the waste package subsystem. The cumulative radionuclide-release values at the waste package subsystem boundary that were used to construct Figures 6-19 through 6-21 are given in Table 6-28. The curves in Figure 6-17 are the expected values of the cumulative release; the vertical bar at the end of each curve is the three-standard deviation interval. Table 6-28 shows that, for assumed uniform probability distributions for radionuclide solubilities, the predicted release is approximately 0.07 (i.e., less than 10 percent) of the U.S. Environmental Protection Agency (EPA, 1985) limits.

6.4.2.4.6 Conclusions

The quantitative results presented in Tables 6-27 and 6-28 are dependent on the data and assumptions used in the analysis. As has been pointed out, only limited data are available to infer probability distributions of the various parameters (e.g., corrosion rate, radionuclide solubilities, and sorption coefficients). The information used to generate the results of Tables 6-27 and 6-28 are based on the combination of available data and technical judgment. In addition, some parts of the analysis, particularly those relating to corrosion-rate calculation, are expected to change as better understanding of the container failure mechanism is obtained through

Table 6-27. Fractional radionuclide-release rates at the waste package subsystem boundary at 90-percent probability

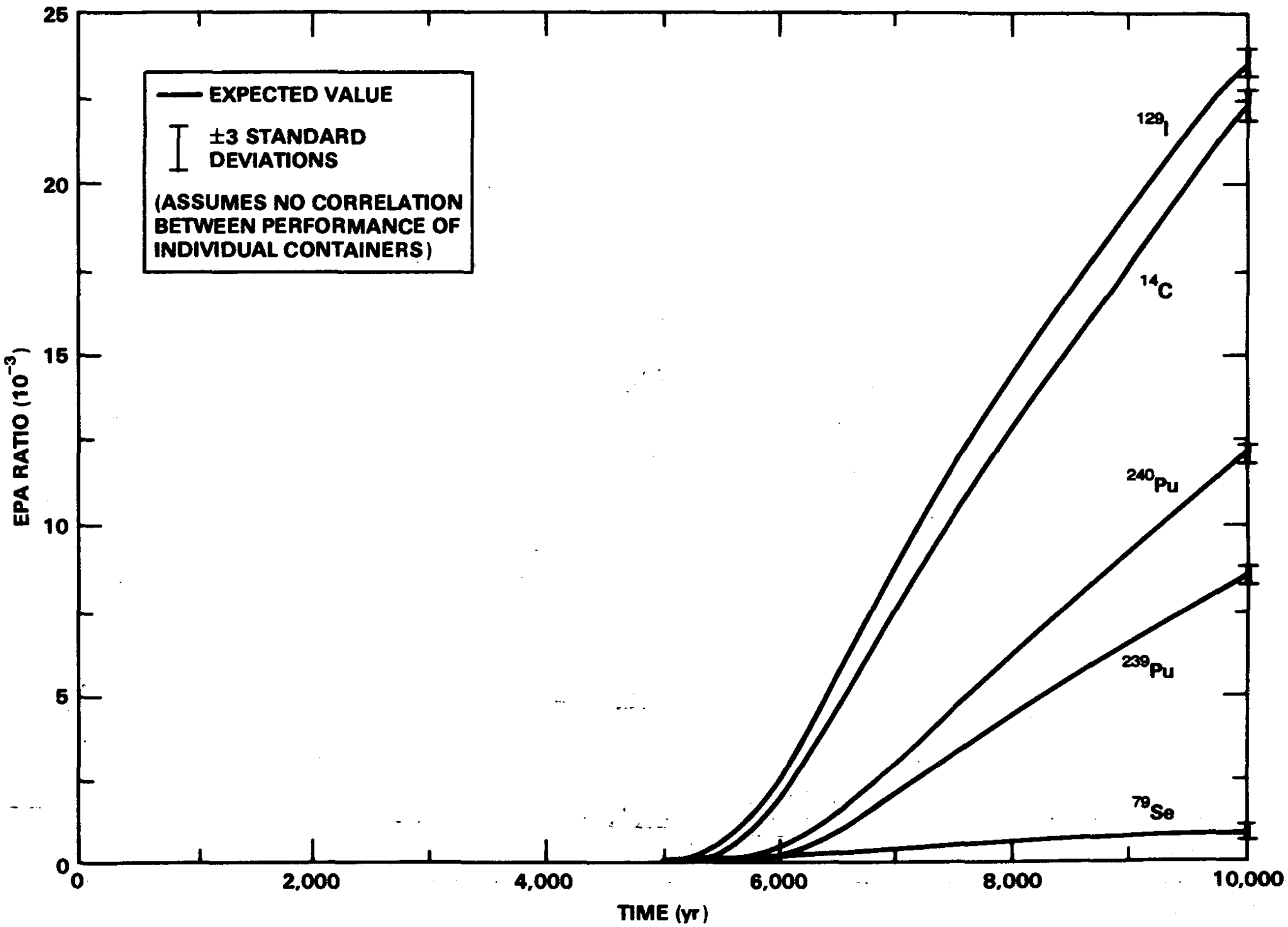
Radionuclide	Annual allowable release-rate limits[a]	Probability distributions for radionuclide solubility values[b]		
		Uniform	Loguniform	Lognormal
Carbon-14	2.4×10^{-5}	9.06×10^{-7}	2.64×10^{-7}	1.10×10^{-7}
Iodine-129	4.8×10^{-4}	1.87×10^{-5}	1.43×10^{-5}	1.24×10^{-5}
Selenium-79	4.6×10^{-5}	9.43×10^{-7}	3.17×10^{-7}	1.77×10^{-7}
Tin-126	3.3×10^{-5}	5.18×10^{-8}	9.08×10^{-9}	1.59×10^{-9}
Technetium-99	1.0×10^{-5}	1.28×10^{-7}	2.57×10^{-8}	5.86×10^{-9}
Americium-241	1.0×10^{-5}	5.63×10^{-14}	c	c
Neptunium-237	1.5×10^{-5}	1.47×10^{-9}	c	c
Plutonium-239	1.0×10^{-5}	8.90×10^{-10}	c	c
Plutonium-240	1.0×10^{-5}	8.61×10^{-10}	c	c
Plutonium-242	1.0×10^{-5}	1.25×10^{-10}	c	c
Radium-226	1.6×10^{-2}	4.19×10^{-7}	c	c

NOTE: Fractional release rate equals (curies per year release rate) divided by (curie inventory at 1,000 years). No credit taken for the contribution to waste package subsystem performance provided by spent fuel cladding.

[a]Allowable release-rate limits per year are based on Figure 6-13.

[b]Estimated maximum fractional release rate (per year), assuming no performance correlation between individual containers.

[c]Not computed because releases for uniform probability distribution are far below allowable release limits.



EPA = U.S ENVIRONMENTAL PROTECTION AGENCY

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Figure 6-19. Cumulative release of iodine-129, carbon-14, plutonium-239 and -240, and selenium-79 at the waste package subsystem boundary.

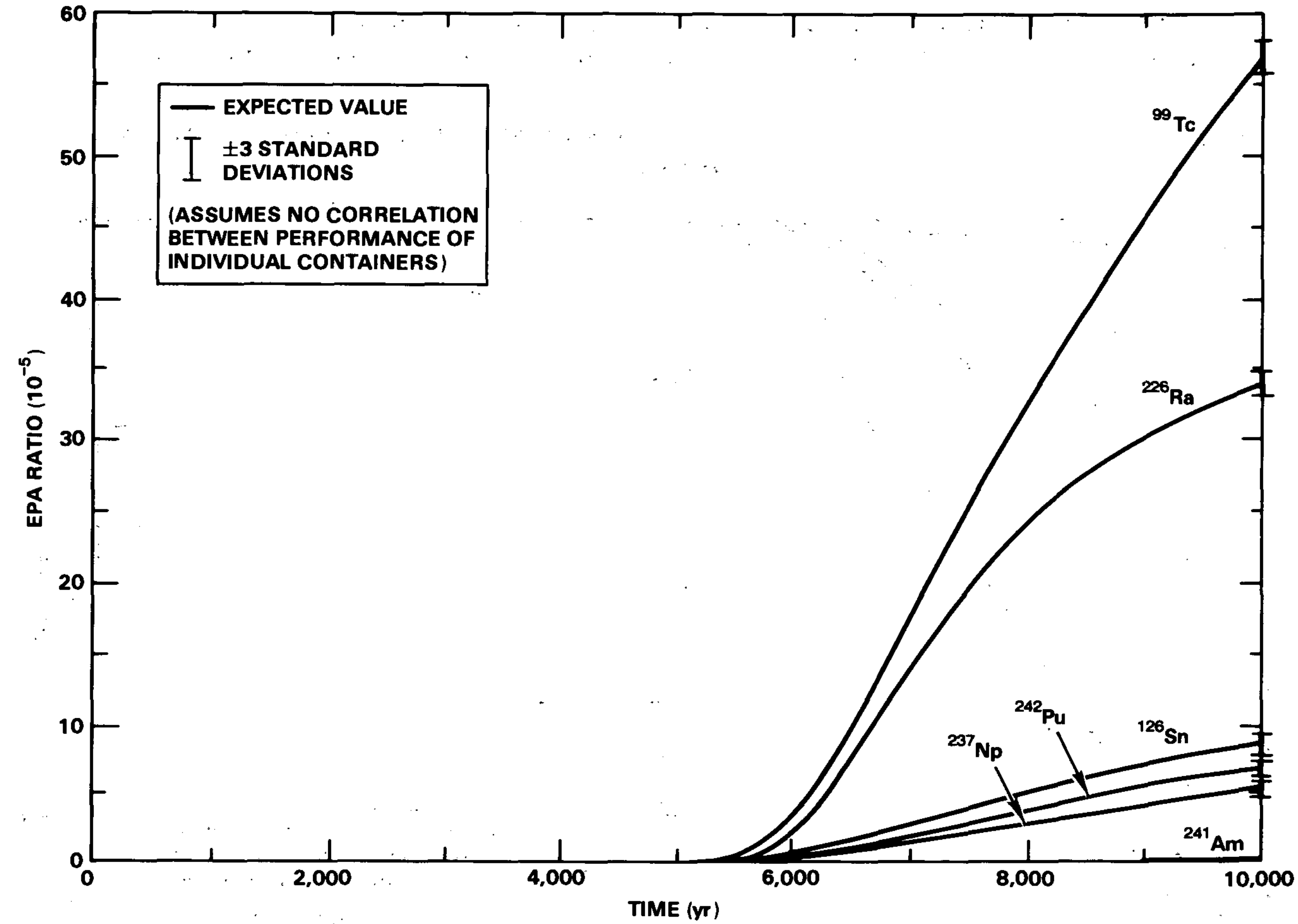


Figure 6-20. Cumulative release of technetium-99, radium-226, tin-126, americium-241, plutonium-242, and neptunium-237 at the waste package subsystem boundary.

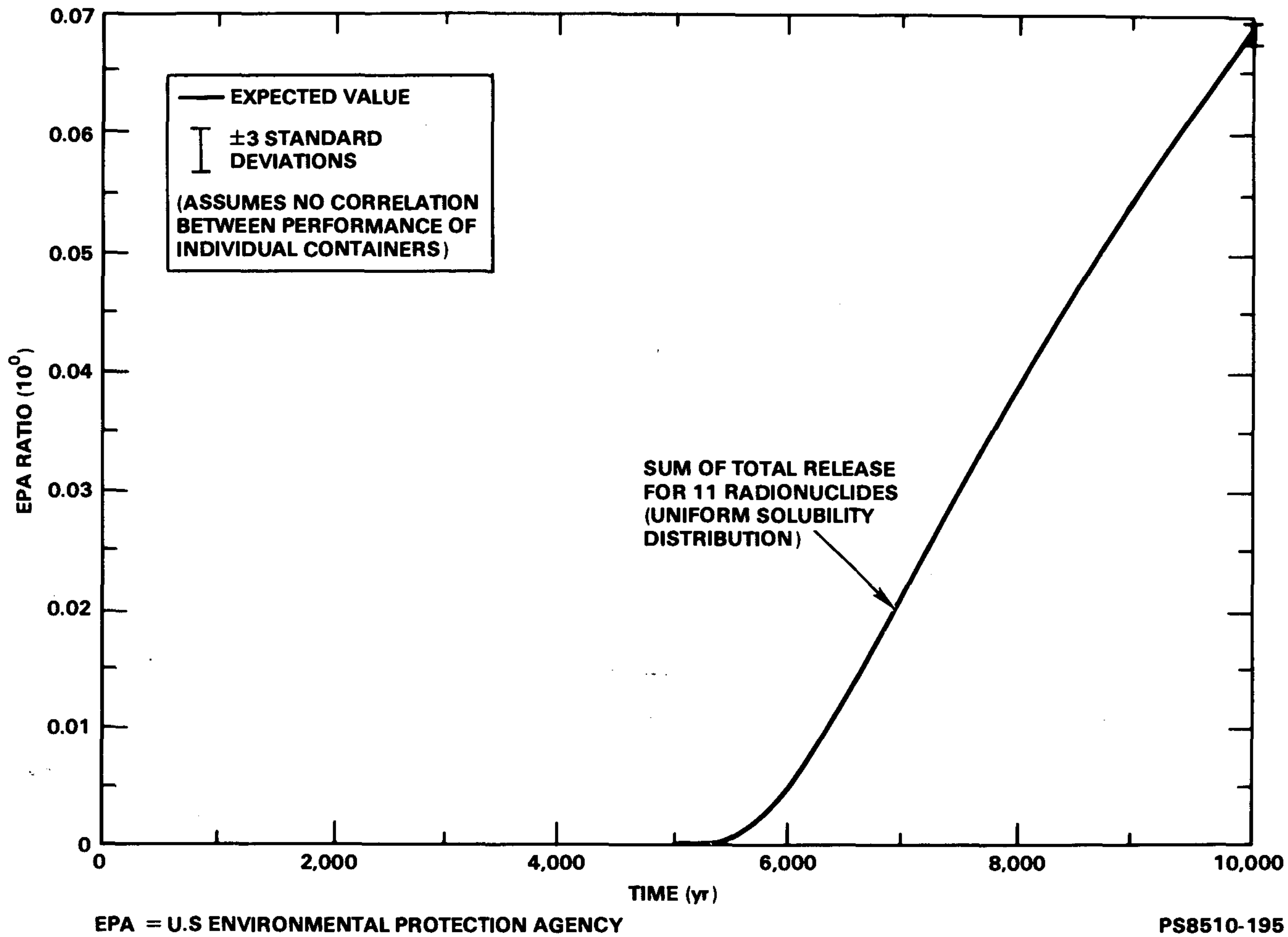


Figure 6-21. Cumulative release of all significant radionuclides at the waste package subsystem boundary.

Table 6-28. Cumulative radionuclide-release rates at the waste package subsystem boundary at 90-percent probability

Radionuclide	Limit,[a] (Ci/MTHM)	Probability distributions for radionuclide solubility values[b]		
		Uniform	Loguniform	Lognormal
Carbon-14	0.1	2.28×10^{-2}	6.63×10^{-3}	2.77×10^{-3}
Iodine-129	0.1	2.40×10^{-2}	1.83×10^{-2}	1.59×10^{-2}
Selenium-79	1	1.13×10^{-3}	3.83×10^{-4}	2.13×10^{-4}
Tin-126	1	8.63×10^{-5}	1.51×10^{-5}	2.63×10^{-6}
Technetium-99	10	5.82×10^{-4}	1.16×10^{-4}	2.69×10^{-5}
Americium-241	0.1	1.20×10^{-6}	c	c
Neptunium-237	0.1	5.56×10^{-5}	c	c
Plutonium-239	0.1	8.81×10^{-3}	c	c
Plutonium-240	0.1	1.24×10^{-2}	c	c
Plutonium-242	0.1	6.98×10^{-5}	c	c
Radium-226	0.1	3.47×10^{-4}	c	c

NOTE: No credit taken for the contribution to waste package subsystem performance provided by spent fuel cladding. Assumed no performance correlation between individual containers.

MTHM = metric tons of heavy metal.

[a]U.S. Environmental Protection Agency limits (EPA, 1985) on the cumulative release at the accessible environment boundary.

[b]Estimated total cumulative radionuclide release, as a fraction of the U.S. Environmental Protection Agency limit (EPA, 1985) during 10,000 years.

[c]Not computed since releases are far below U.S. Environmental Protection Agency (EPA, 1985) total cumulative release limits.

long-term corrosion tests. Several assumptions in the analysis were made that introduce conservatism and resulted in prediction of greater than expected peak fractional release rates and cumulative releases. These assumptions include (1) neglecting the barriers to radionuclide dissolution that are provided by zircaloy fuel cladding and spent fuel matrix and (2) postulation that sufficient oxygen is available to corrode all containers at an undiminished rate. It is not clear whether the assumption that corrosion occurs uniformly over the entire surface of the container is conservative. Other conditions being constant, the distribution of container failures in time is nonconservative, in the sense that the failure of all containers at the same time would result in a higher fractional release-rate peak.

In view of the above comments, it is apparent that final, quantitative conclusions regarding performance of the waste package subsystem cannot be drawn at this time. However, it can be qualitatively stated that

- Based on a simplified empirical model and considering failure by uniform corrosion only, the preliminary estimates of container lifetime provide no indication that the container will not last for longer than 300 to 1,000 years.

- There is no indication that the U.S. Nuclear Regulatory Commission criterion for maximum fractional release rate from the engineered barrier system cannot be met.

- There is a high probability that the waste package subsystem could act as a diverse and independent barrier (in addition to the principal barrier--the site subsystem) to radionuclide migration.

6.4.2.5 Repository seals subsystem performance

The basic function of the repository seals subsystem is to prevent preferential migration of radionuclides to the accessible environment along man-induced pathways. The barrier components of this subsystem, which are described in Subsection 6.4.2.2.2, are located between the waste package and site subsystems. Pathways in the repository seals subsystem are through emplacement room backfill and underground opening seals and (or) the damaged rock zone surrounding the excavation. It is expected that low-permeability seals can be designed to restrict ground-water movement through the access and ventilation drifts that connect the emplacement rooms and shafts. In the shafts and in drifts where such low-permeability seals are placed, the fastest path is expected to be through the damaged rock zone adjacent to the shafts and drifts.

In this subsection, potential cumulative radionuclide release through the damaged rock zone is assessed. The assessment is based on probabilistic computer simulations of potential release during a 10,000-year period after closure.

6.4.2.5.1 Methodology for repository seals subsystem analysis

The approach developed for probabilistic evaluation of the repository seals subsystem is to calculate cumulative release during 10,000 years at the designated subsystem boundary, with release expressed in terms of the limits stated in 40 CFR 191 (EPA, 1985). Time-dependent releases predicted for the waste package (see Subsection 6.4.2.4) are used as input for this analysis of the repository seals subsystem. Radionuclide transport is assumed to take place by ground water flowing preferentially through the damaged rock zone of the repository seals subsystem.

The calculation of radionuclide release from the repository seals subsystem is based on a conceptual model discussed below. Release from the repository seals subsystem is calculated at an arbitrary boundary located at the intersection of the shafts with the Vantage interbed at the top of the Grande Ronde Basalt (see Fig. 3-6), a distance of approximately 133 meters (436 feet) above the emplaced waste. This analysis conservatively assumes that 10 percent of the contaminated ground-water flow is through the repository seals subsystem pathway and 90 percent through the site subsystem. A three-dimensional analysis of flow pathways for a repository in the basalt (Golder, 1983a) estimated that only approximately 0.1 to 2.0 percent of the vertical ground-water flow entering the repository area would move laterally and enter the shafts at the repository level. In addition, approximately 0.2 to 6.5 percent of the ground water would flow across the repository area and could traverse the emplacement horizon and then enter the shafts by indirect pathways (Golder, 1983a). Similar three-dimensional ground-water flow simulations (Cottam, 1983) have also suggested that less than 1 percent of the total ground-water flow through the repository is likely to enter the repository seals subsystem pathway. Since these calculations were based on limited data on rock characteristics, the more conservative value of 10 percent was used for purposes of predicting the contribution of the repository seals to cumulative radionuclide release at the accessible environment.

Radionuclide migration along the repository seals subsystem pathway is assumed to be through the damaged annulus of rock around the shafts and around the access drifts connecting the shafts to the emplacement rooms, rather than through the backfill material placed in these openings at repository closure. This assumption is believed reasonable, because, for the relative ranges of hydraulic properties (hydraulic conductivity and effective porosity) expected for the damaged rock and backfill, ground-water velocity will be greater through the damaged rock zone than through the backfill. The calculation of ground-water travel times through the repository seals subsystem was based on Darcy's law, which relates ground-water velocity to effective porosity, hydraulic conductivity, and hydraulic gradient. No credit was taken for ground-water travel time through the emplacement rooms, since it was assumed these rooms would be left open or backfilled with a porous crushed rock with no bentonite added. The dominant hydraulic gradient near the repository is in a vertical direction due primarily to thermal effects from the emplaced waste. Thus, the magnitude of the hydraulic gradient will decrease with time, approaching the natural hydraulic gradient after long time periods. Therefore, the radionuclide-release rate and ground-water velocity through the shaft are also time dependent and were modeled as such.

Radionuclide release at the intersection of the shafts with the Vantage interbed, attributable to radionuclide migration through the repository seals subsystem, was calculated using the probabilistic computer code REPSTAT, the methodology of which is described in Fredenburg and Sonnichsen (1985). In the analysis summarized herein, the peak release rate from the waste package subsystem analysis (see Table 6-27) is used as input to the repository seals subsystem analysis. The magnitude of the peak radionuclide-release rates predicted by the CHAINT-MC (Baca et al., 1984b; Kline et al., 1986) computer code were modeled as discrete variables. The parameters affecting radionuclide travel time were treated as random rather than discrete variables. Probability distributions were then assigned to these variables to represent uncertainty. A Monte Carlo sampling technique was then used to select values from the distributions as inputs to mathematical models for calculation of release and transport of radionuclides. The output of these computer simulations is a cumulative probability curve for total radionuclide release constructed from the spectrum of predicted releases at the Vantage interbed.

The release rates (see Fig. 6-16 through 6-18) generated by the CHAINT-MC computer code were conservatively approximated by step functions, with constant release rate equal to the peak release rate, at 90 percent probability (from Table 6-27). This rate was assumed to start at 4,500 years after closure and continue to 10,000 years or until the inventory was exhausted.

Radionuclide travel time is calculated for average path lengths to the designated release boundary (Vantage interbed) from each of 10 panels that collectively represent one quadrant of the repository. No credit is taken for travel time through the emplacement rooms, since it is assumed a highly conductive backfill would be placed in those rooms. The cumulative radionuclide release at the Vantage interbed during 10,000 years is calculated for each panel and then summed for all 10 panels to yield the cumulative release during 10,000 years for one quadrant of the repository. The cumulative release for the repository is then conservatively assumed to be equal to four times the release for one quadrant. This approach is conservative, because, for likely hydraulic gradient vectors, only one quadrant can be expected to contribute to transport of radionuclides toward the vertical shafts. This calculation is repeated for 1,000 Monte Carlo trials for parameters governing radionuclide-transport rates randomly sampled from the probability distributions of parameter values (see Tables 6-25 and 6-29) for 1,000 Monte Carlo trials.

Table 6-29. Data set for assessment of the repository seals subsystem

Parameter	Median value	Distribution	Standard deviation[a]
	Hydraulic gradient[a,b]		
Constant horizontal	5.0×10^{-4}	Lognormal	1.0
Constant vertical	10^{-3}	Lognormal	1.0
Thermal-induced vertical (initial value)	2.9×10^{-2}	Lognormal	1.0
Half-life of thermal decay	1,100 yr	Lognormal	1.0
Hydraulic conductivity (K)[c]	10^{-10} to 10^{-6} m/s $\sim 10^{-5}$ to $\sim 10^{-1}$ ft)	Lognormal	2.3
Effective porosity[c]	0.001 to 0.022[d]	(e)	(e)
Adsorption coefficients[b]	(see Table 6-25)	Uniform	(f)
	Repository geometry[g]		
Drift lengths	400 to 1,750 m (1,310 to 5,740 ft)	Discrete	(f)
Shaft path length (to Vantage interbed)	133 m (436 ft)	Discrete	(f)

[a]Standard deviation for the normal distribution of the natural logarithm of the parameter, except where otherwise indicated.

[b]Based on technical judgment.

[c]In zone of damaged rock around repository seals subsystem.

[d]Value derived from $2.15 \times K^{1/3}$(meters per second) after Snow (1968).

[e]Distribution of parameter is governed by distribution of input variables.

[f]Not applicable.

[g]Raymond Kaiser Engineers, Inc./Parsons Brinckerhoff Quade & Douglas, Inc. (RKE/PB, 1984b).

6.4.2.5.2 Data set for repository seals subsystem

The data used in this preliminary performance assessment of the repository seals subsystem are given in Table 6-29. Cumulative probability curves for cumulative radionuclide release were generated for median hydraulic conductivities of 10^{-10}, 10^{-9}, 10^{-8}, 10^{-7}, and 10^{-6} meter per second (approximately 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}, and 10^{-1} foot per day) in the damaged rock zone (Cottam, 1983).

6.4.2.5.3 Results of repository seals subsystem analysis

The probabilities for cumulative radionuclide release from the repository seals subsystem are shown in Figure 6-22. The vertical axis of the graph is the probability that the cumulative release of all radionuclides at the subsystem boundary (during 10,000 years) is less than or equal to the value on the horizontal axis (expressed as fractions of the U.S. Environmental Protection Agency limit (EPA, 1985)).

Separate distribution functions were generated for different median values of hydraulic conductivity in the damaged rock zone to assess the sensitivity of radionuclide releases to this parameter. For a median hydraulic conductivity of 10^{-10} meter per second (approximately 10^{-5} foot per day), less than 1 percent of the Monte Carlo trials predicted releases greater than zero during 10,000 years. This result corresponds to the nearly horizontal line at the top of Figure 6-22. The distribution functions (cumulative release curves) for the cases tested are labeled with the median hydraulic conductivity assumed for the damaged rock zone. The mean cumulative release (i.e., average of predicted releases in 1,000 Monte Carlo trials) for the cases analyzed are given in Table 6-30. These results are dependent on the assumed parameter distributions used in the analysis and the magnitude of the waste package release rate used as a discrete input value. However, based on these results and considering the likely conservatism in the analysis, the probability of exceeding the U.S. Environmental Protection Agency (EPA, 1985) standard due to migration of radionuclides through the repository seals subsystem is low. Table 6-30 also expresses cumulative release from the repository seals subsystem as a fraction of the cumulative source term that potentially could be released by the repository seals (i.e., cumulative release from the waste package multiplied by the assumed contaminated flow fraction, 10 percent, migrating through the repository seals). These results indicate that, for higher values of hydraulic conductivity, the damaged rock zone would not be an effective barrier to radionuclide migration.

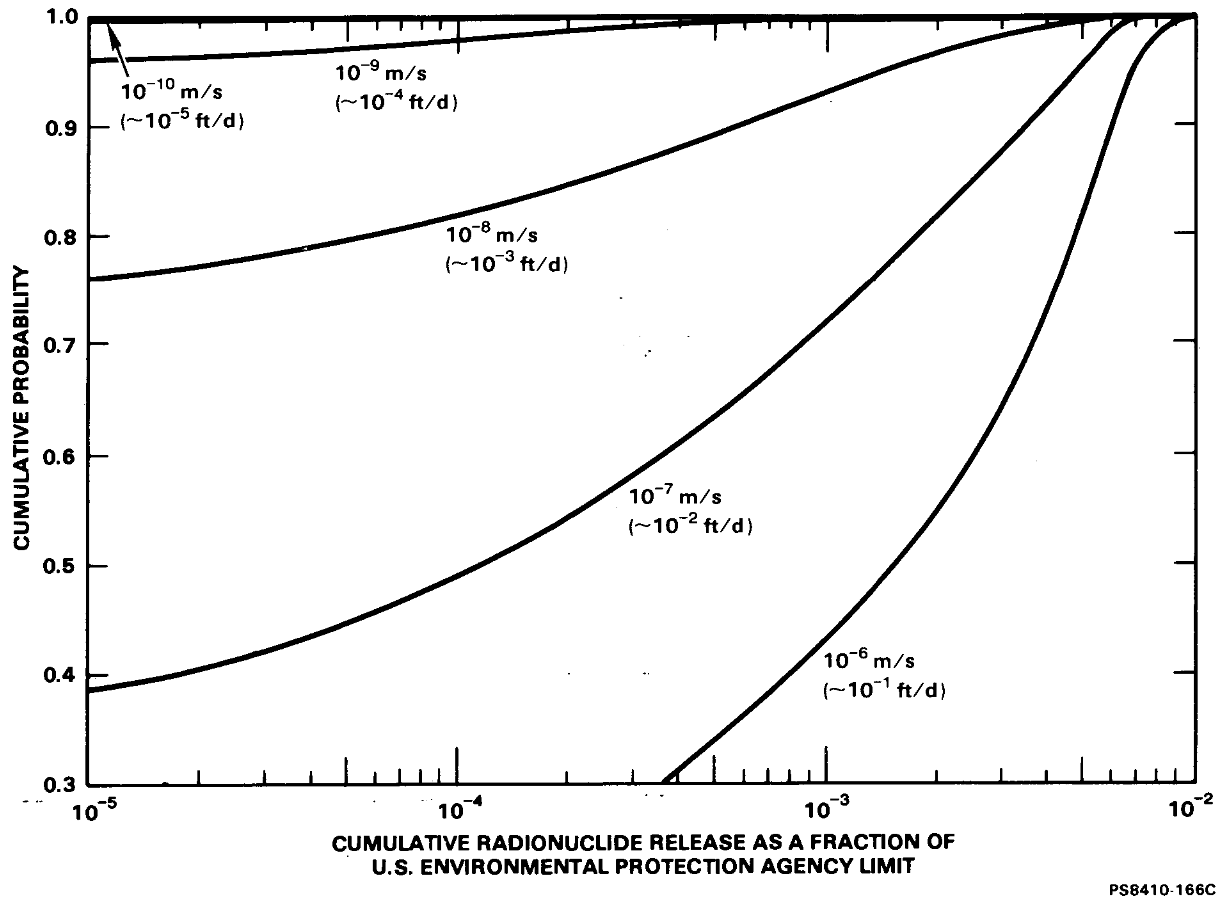


Figure 6-22. Cumulative release of all radionuclides during 10,000 years at the repository seals subsystem boundary for various median values of hydraulic conductivity in the damaged rock zone.

Table 6-30. Mean cumulative release of all radionuclides at the repository seals subsystem boundary during 10,000 years

Mean hydraulic conductivity in the damaged rock zone, m/s (ft)	Release[a]	Release fraction[b]
10^{-10} ($\sim 10^{-5}$)	2.8×10^{-8}	2.7×10^{-6}
10^{-9} ($\sim 10^{-4}$)	1.1×10^{-5}	1.0×10^{-3}
10^{-8} ($\sim 10^{-3}$)	2.2×10^{-4}	2.1×10^{-2}
10^{-7} ($\sim 10^{-2}$)	1.0×10^{-3}	9.4×10^{-2}
10^{-6} ($\sim 10^{-1}$)	2.4×10^{-3}	2.2×10^{-1}

[a]Ratio of calculated release to the U.S. Environmental Protection Agency limit (EPA, 1985).

[b]Ratio of mean calculated cumulative release from the repository seals to the estimated waste package release to the seals subsystem.

6.4.2.6 Site subsystem performance

The site subsystem is the nonengineered component of the repository system consisting of the rock between the edge of the repository and the accessible environment. Performance measures used to gauge the effectiveness of the site subsystem are pre-waste-emplacement ground-water travel times and post-waste-emplacement radionuclide releases to the accessible environment. A preliminary analysis of these two performance measures is presented in this subsection.

According to U.S. Environmental Protection Agency standards governing releases from high-level nuclear waste repositories (EPA, 1985), the term accessible environment means

> ". . . (1) the atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area."

In the same reference, the term controlled area is defined as

> ". . . (1) a surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location."

In the following analyses, the boundary of the accessible environment for the proposed repository beneath the Hanford Site is taken to be the lithosphere and ground surface 5 kilometers (3.1 miles) from the edge of the repository.

6.4.2.6.1 Pre-waste-emplacement ground-water travel time

The objective of this subsection is to establish preliminary estimates of pre-waste-emplacement ground-water travel time for the proposed repository beneath the Hanford Site to assess how well this repository system can comply with the travel-time criteria defined in 10 CFR 960 (DOE, 1984a). To accomplish this objective, a suite of travel-time models, based on data and interpretations of the deep ground-water flow system beneath the Hanford Site, has been developed. These models are used to examine the sensitivity of the predicted ground-water travel times to variations in some of the model inputs and results in a range of predicted travel times. All analyses have been conducted in a stochastic framework, which allows a probability of occurrence to be associated with a predicted travel time. This subsection presents an abbreviated discussion of the travel-time model that best accounts for the current conceptual understanding of the deep ground-water flow regime beneath the Hanford Site. This model is used as a basis for evaluating the basalt sequence in the reference repository location and vicinity against the travel-time criteria in 10 CFR 960. The reader is referred to Clifton (1986) for a detailed discussion of the method of analysis, model inputs and assumptions, and results of the suite of ground-water travel-time models developed in support of this environmental assessment.

Pre-waste-emplacement ground-water travel time to the accessible environment is used by the U.S. Nuclear Regulatory Commission and U.S. Department of Energy as a measure for screening potential high-level nuclear waste repository sites. Both agencies require that the travel time be calculated along a pathline (or pathlines) beginning at the edge of the disturbed zone around the repository. The definition of disturbed zone provided by the U.S. Nuclear Regulatory Commission in 10 CFR 60 (NRC, 1985a) is

> ". . . that portion of the controlled area whose physical or chemical properties have changed as a result of underground facility construction or from heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository."

Creation of a disturbed zone may occur as a result of mechanical, thermal, or chemical processes acting on the host rock around the repository. Therefore, determination of the location and extent of the disturbed zone is site specific, and might best be defined in terms of any significant effects on the performance of the isolation system. Determination of such effects requires detailed subsurface site characterization. Physical changes, caused either by excavation or by thermal stresses induced by the emplaced waste, are likely to modify the permeability of the host rock out to lateral distances of no more than a few times the radius of the excavation. The extent and magnitude of the permeability change are dependent on several factors, including excavation method and temperature change due to waste emplacement. These changes are not likely to affect significantly the repository isolation performance (Cottam, 1983). Hence, the expected extent of the disturbed zone is a small portion of the total distance separating the repository from the accessible environment.

One characteristic of the repository in the postclosure period is the elevated temperature field produced by the decaying nuclear waste. This temperature field induces dominantly upward hydraulic gradients (i.e., buoyant gradients) above the repository. The magnitude of these gradients will decrease as a function of time, because the rate of heat production diminishes with time. The magnitude of these gradients will also decrease as a function of distance from the waste due to temperatures decreasing with distance. Preliminary modeling studies of coupled heat transport and ground-water flow suggest that travel times through the proposed candidate horizons could be sufficiently long for the magnitudes of the thermal-induced hydraulic gradients to decline to a point where they have no significant effect on the ground-water flow paths and travel times in the basalt flow tops overlying the proposed candidate horizons (Long and WCC, 1984).

In all the analyses of pre-waste-emplacement ground-water travel time presented in Clifton (1986) and in this subsection, the boundary of the disturbed zone is not rigorously defined, because of the factors discussed in the preceding paragraphs. It is implicitly assumed that the boundary of the disturbed zone lies between the repository excavations and the starting location of pathlines used to calculate ground-water travel times. Defining the extent of the disturbed zone is dependent on data and analyses that would be available, if the reference repository location were recommended for site characterization.

Site description

The deep basalts beneath the Hanford Site form a layered sequence consisting of dense, fractured basalt flow interiors overlain by brecciated and vesicular flow tops (see Section 2.1.1 and Subsection 3.3.2.1). Some of the basalt flows are relatively thick (greater than 40 meters (130 feet)) and continuous for many kilometers (miles) (Myers, Price et al., 1979). The permeability of flow interiors is lower than flow tops, because of their much smaller volume of interconnected fracture and pore space. In addition, most of these fractures are filled or lined with secondary minerals. The lithostatic load, in situ stress, and secondary minerals are thought to contribute to the lower permeability of deep flow interiors compared to shallower basalts (Spane, 1982). Thus, the flow interiors tend to act as confining units for ground water contained in the flow tops. The permeability contrast between basalt flow tops and flow interiors promotes two-dimensional horizontal movement of ground water along flow tops and one-dimensional vertical movement of ground water through flow interiors.

Various concepts of the ground-water flow regime in the deep basalt sequence beneath the Hanford Site are discussed in Subsection 3.3.2.2. These concepts depict four flow regimes that range between an essentially confined ground-water flow system with low vertical leakage across dense interiors and a system with high vertical leakage across flow interiors and along discrete structural discontinuities. Recent analyses of hydrochemical data from the deep ground waters beneath the reference repository location are supportive of the concept that some vertically upward movement of ground water has been and is occurring in the deep basalt sequence (see Section 3.2.2). Whether this vertical movement of ground water is occurring uniformly across the basalt sequence or in local areas along one or more structural discontinuities is not known at this time. Site-characterization studies would be expected to determine the rates and extent of the vertical movement of ground water in the deep basalts beneath the reference repository location.

Ground-water travel-time models

In the ground-water travel-time analyses developed in support of this environmental assessment (Clifton, 1986), a series of five models is used to account for the different concepts describing the ground-water flow regime in the deep basalts. The simplest of these models considers only horizontal flow of ground water in the Cohassett flow top and neglects any vertical component of ground-water flow through the overlying basalt sequence. Additional complexity is introduced by superimposing on this model various amounts of vertical ground-water flow. The model with the largest amount of vertical ground-water flow represents a basalt sequence where the flow interiors act as weak, confining units for ground water in the basalt flow tops.

The five ground-water travel-time models presented in Clifton (1986) are as follows:

- Travel time only in a basalt flow top.
- Travel time only in a section of the flow interior above the repository immediately beneath the overlying flow top.
- Travel time in the section of flow interior in Model 2 and the flow top in Model 1.
- Travel time in a layered sequence of basalt flow tops and flow interiors overlying the Cohassett flow interior (ground-water particles tracked from the base of the flow top immediately overlying the Cohassett flow interior).
- Travel time in a layered sequence of basalt flow tops and flow interiors overlying the Cohassett flow interior (ground-water particles tracked from within the interior of the Cohassett flow).

These models are schematically illustrated in Figure 6-23. The main reason for developing the suite of travel-time models is to examine the sensitivity of the predicted travel times to different concepts of the deep ground-water flow system and various assumptions about required model inputs.

The deep ground-water flow system in all of the above models is assumed to be steady state. There appears to be little justification for assuming that the deep ground-water flow system is nonsteady state

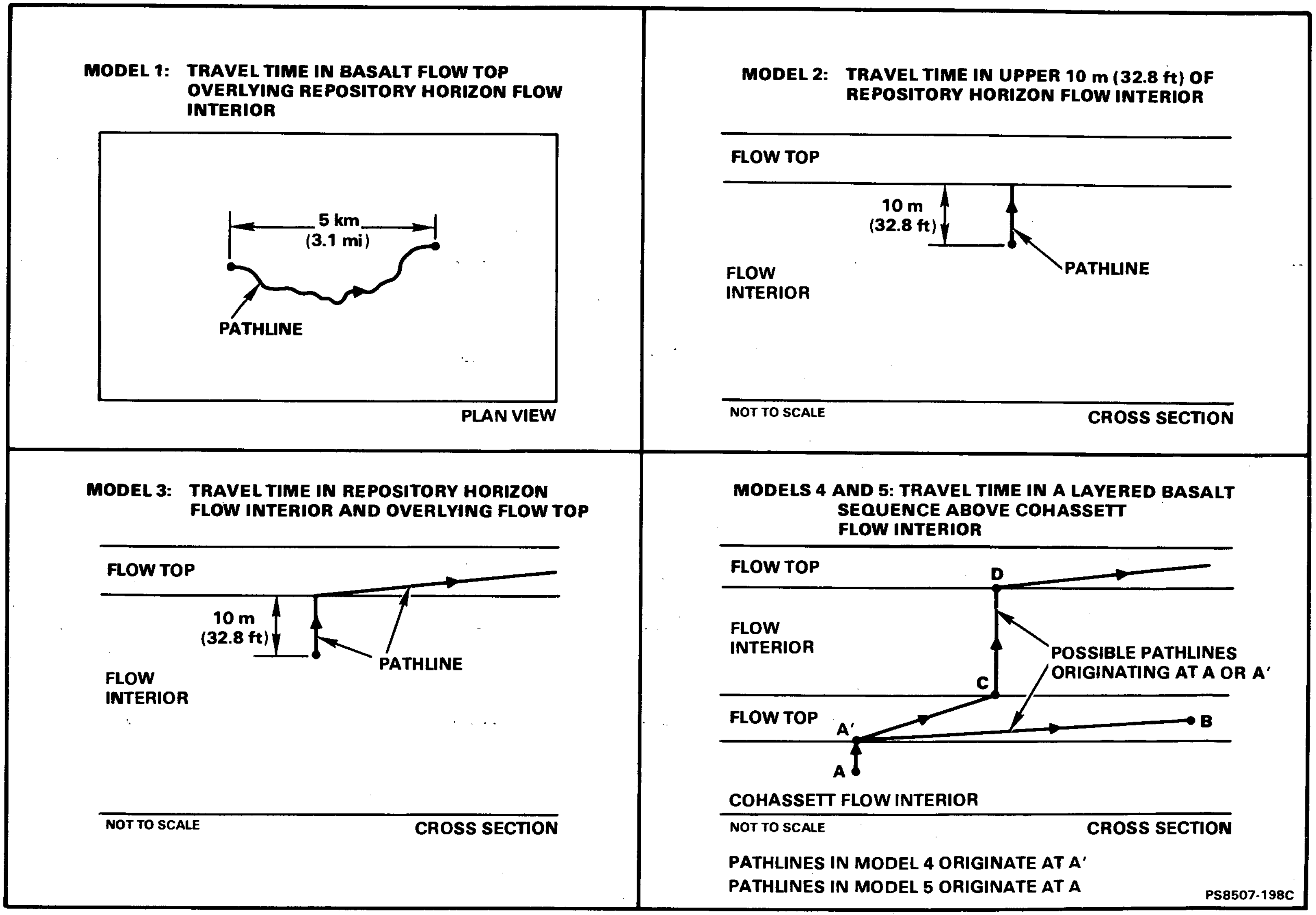


Figure 6-23. Depiction of ground-water flow regimes in models for analyzing pre-waste-emplacement travel times.

for the purposes of calculating pre-waste-emplacement ground-water travel times. This is due to the apparent isolation of the shallow and deep ground-water flow systems beneath the reference repository location from hydraulic stresses evident away from the vicinity of the reference repository location (see Section 3.2.2). Thus, the models presented in Clifton (1986) and in this subsection evaluate the pre-waste-emplacement ground-water travel times assuming the prevailing deep ground-water flow system does not change with time (see Section 6.3.1).

Models 1, 2, and 3 can be considered to apply to any of the proposed candidate horizons (see Section 2.2.3). Models 4 and 5, however, are developed for the Cohassett flow and the sequence of basalt flows above the Cohassett flow.

Models 4 and 5 explicitly account for the horizontal and vertical components of ground-water flow in a layered basalt sequence, and are the models most consistent with the conceptual understanding of the deep ground-water flow system beneath the reference repository location and vicinity. The principal difference between these two models is the location of the starting points of pathlines used to calculate travel times. In Model 4, pathlines begin at the base of the Cohassett flow top. Pathlines in Model 5, however, begin in the upper portion of the Cohassett flow 10 meters (32.8 feet) below the base of the flow top. Model 5 demonstrates how, accounting for some component of ground-water flow in the Cohassett flow interior increases the total travel times above those predicted by Model 4.

The following is a brief discussion of the inputs to and results of Model 4. These results are used as a basis for the findings on the geohydrology guideline (see Subsection 6.3.1.1). The purpose of neglecting any component of travel time in the Cohassett flow interior in the results used to evaluate the site with the travel-time criteria in the General Siting Guidelines is to introduce conservatism. The U.S. Department of Energy is maintaining the future option of taking some credit for ground-water travel time in the Cohassett flow interior.

Method of analysis. The modeling of ground-water travel times in a layered sequence of basalt flow tops and flow interiors is accomplished in Model 4 by separately modeling the vertical and horizontal components of ground-water flow. It is possible to model these flow components separately, because the high contrast between the permeabilities of basalt flow tops and flow interiors causes essentially two-dimensional horizontal movements of ground water in the flow tops and one-dimensional vertical movement of ground water in the flow interiors. Clifton (1986) presents a detailed discussion of the methods of analysis and assumptions used in all travel-time models developed for this environmental assessment.

The results in Clifton (1986) and in this subsection are presented in the form of probability distributions, which allow a probability (likelihood) to be associated with a particular ground-water travel time. This, in turn, allows an assessment of how well the site can comply with the travel-time criteria in the General Siting Guidelines (DOE, 1984a). Travel-time probability distributions are developed by explicitly taking into account uncertainties in the model inputs. These uncertainties are due to a number of factors, which can include lack of geohydrologic knowledge and spatial variability. The uncertainties in the model inputs are also described by probability distributions, which require various statistical parameters to be specified. These statistics are derived from sample data where possible or, where data are lacking, from judgment or from solicitation of technical opinion (e.g., Runchal et al., 1984a, 1984b).

The uncertainties in the model inputs are propagated through the ground-water flow and travel-time equations by means of a Monte Carlo technique (Clifton, 1985). These equations are numerically solved with the computer code PORMC-SF, which is a Monte Carlo version of the computer code PORFLO (Kline et al., 1983; Runchal et al., 1986). PORFLO solves the fully coupled ground-water flow, heat transfer, and mass transport equations in two dimensions by means of an integrated finite-difference numerical scheme. PORMC-SF solves the steady-state, two-dimensional ground-water flow equation. Travel times are analytically calculated in PORMC-SF from the seepage velocity field after the ground-water flow equation is solved.

Inputs for travel-time analysis. The inputs required to predict pre-waste-emplacement ground-water travel times by Model 4 can be grouped into (1) parameter fields, (2) boundary conditions, and (3) layer thicknesses. Only the parameter fields are modeled as being uncertain (i.e., described by probability distributions). The boundary conditions and layer thicknesses in the model are deterministically set. This is because the predicted ground-water travel times are particularly sensitive to the parameter fields, and these fields are the most uncertain of the required model inputs. Clifton (1986) discusses in detail the inputs to all ground-water travel-time models developed for this environmental assessment.

The parameter fields in Model 4 are (1) flow-top transmissivity, (2) flow-top effective thickness, (3) flow interior vertical hydraulic conductivity, and (4) flow interior effective porosity. Table 6-31 lists the probability distributions used to describe the parameter fields and the bases for determining these distributions. Wherever possible, data were used as a basis for these distributions; however, when data were scarce, judgment or the results of technical opinion surveys were used. In particular, judgment was used to estimate the log-transmissivity correlation range in the flow tops and vertical to horizontal hydraulic conductivity anisotropy ratio in the flow interiors. These two components of the parameter fields in Model 4 are varied over conservative ranges to examine the effects on the predicted ground-water travel times. One of the statistical assumptions made in Model 4 is that the same parameter fields in different layers are independent and identically distributed.

Boundary conditions are used to impose regional (i.e., horizontal) and vertical hydraulic gradients across the basalt sequence of Model 4. These gradients are estimated from hydraulic head data that have been collected at three nested piezometer sites around the reference repository location since April 1984 and from hydraulic heads measured in deep boreholes in the Cold Creek syncline. Section 3.3.2 discusses these data in more detail. The deterministic estimates of horizontal and vertical

Table 6-31. Parameter field probability distributions for pre-waste-emplacement ground-water travel-time model

Parameter field	Probability distribution	Basis*
Flow-top transmissivity (T)	Lognormal Median = 0.15 m^2/d (1.6 ft^2/d) Standard deviation of $\log_{10}(T)$ = 1.83 Correlation range of $\log_{10}(T)$ = (0, 2, and 5 km (0, 1.2, and 3.1 mi))	Available data used to estimate median and log-standard deviation. Judgment used to estimate log-transmissivity correlation range.
Flow-top effective thickness	Uniform Range 10^{-3} to 10^{-1} m (10^{-3} to 10^{-1} ft)	Judgment, technical opinion surveys, and data from core samples.
Flow interior vertical hydraulic conductivity (K_V)	Lognormal Median = 5.0×10^{-13} m/s (1.4×10^{-7} ft/d), 1.5×10^{-12} m/s (4.2×10^{-7} ft/d), and 1.5×10^{-11} m/s (4.2×10^{-6} ft/d) Standard deviation of $\log_{10}(K_V)$ = 0.90	Derived from horizontal hydraulic conductivity data by assuming constant vertical to horizontal anisotropy ratios of 1, 3, and 30.
Flow interior effective porosity (n_e)	Lognormal Median = 10^{-4} Standard deviation of $\log_{10}(n_e)$ = 0.51 (95 percent of range between 10^{-5} and 10^{-3})	Judgment and data from core samples.

*See Clifton (1986) for detailed discussion.

hydraulic gradient used in Model 4 are 2×10^{-4} and 1×10^{-3}, respectively. The direction of vertical ground-water flow is upward across the Grande Ronde Basalt sequence in the reference repository location.

The stratigraphic thicknesses of the layers in the basalt sequence above the Cohassett flow interior used in Model 4 are listed in Table 6-32. These thicknesses are derived from Cross and Fairchild (1985) and Landon (1985), and are the arithmetic means of the stratigraphic thicknesses of the respective layers in 11 boreholes in and around the reference repository location. Model 4 requires each layer in the sequence to have a lateral uniform thickness.

Principal results. Figures 6-24 through 6-26 show the distributions of pre-waste-emplacement ground-water travel times predicted by Model 4 for a basalt flow top with log-transmissivity correlation ranges of 0, 2, and 5 kilometers (0, 1.2, and 3.1 miles), respectively. Travel-time distributions in these figures are given for anisotropy ratios of vertical to horizontal hydraulic conductivity in the flow interiors of 1, 3, and 30. The ratios of 1 and 3 are considered to be nominal and the ratio of 30 is considered to be reasonably extreme. The distributions in Figures 6-24 through 6-26 are quite similar for travel times of less than about 20,000 years. This indicates that the relatively short travel times are insensitive to variations in the log-transmissivity correlation range in the flow tops and the hydraulic conductivity and anisotropy ratio in the flow interiors.

The probabilities that pre-waste-emplacement ground-water travel time will exceed 1,000 and 10,000 years are the results of primary interest for evaluating the site against the travel-time conditions in the geohydrology guideline (see Subsection 6.3.1.1). These exceedance probabilities are measures of the likelihoods that travel times will exceed 1,000 and 10,000 years. The estimated exceedance probability for a travel time of 1,000 years ranges between 0.97 and 0.99. For a travel time of 10,000 years the estimated exceedance probability lies between 0.78 and 0.81. Mean travel times ranged between 22,000 and 940,000 years and median travel times ranged between 22,000 and 73,000 years. In determining the exceedance probabilities, travel time through the Cohassett flow interior is not taken into account. Clifton (1986) presents results demonstrating that significant increases in the estimated pre-waste-emplacement travel times occur when travel time is accounted for in the Cohassett flow interior. For example, taking into account the travel time through the upper 10 meters (33 feet) of the Cohassett flow interior increases the probabilities of travel times exceeding 1,000 and 10,000 years to at least 0.99 and 0.95, respectively, for nominal values of the vertical to horizontal hydraulic conductivity anisotropy ratio in the flow interiors.

These results are considered to be preliminary, because of the current status of the data base used in the analysis. The prediction of pre-waste-emplacement ground-water travel times for the reference repository location would continue as more data are collected during site characterization and as the conceptual model of the deep ground-water flow

Table 6-32. Stratigraphic layers and thicknesses for pre-waste-emplacement ground-water-travel-time models

Layer	Thickness m (ft)
Lower Frenchman Springs flow interior	16.3 (53.5)
Vantage interbed and Grande Ronde #1 flow top	8.6 (28.2)
Grande Ronde #1 flow interior	7.8 (25.6)
Grande Ronde #2 flow top	6.1 (20.0)
Grande Ronde #2 flow interior	17.9 (58.7)
Rocky Coulee flow top	6.0 (19.7)
Rocky Coulee flow interior	34.1 (111.9)
Cohassett flow top	8.6 (28.2)

NOTE: After Cross and Fairchild (1985) and Landon (1985).

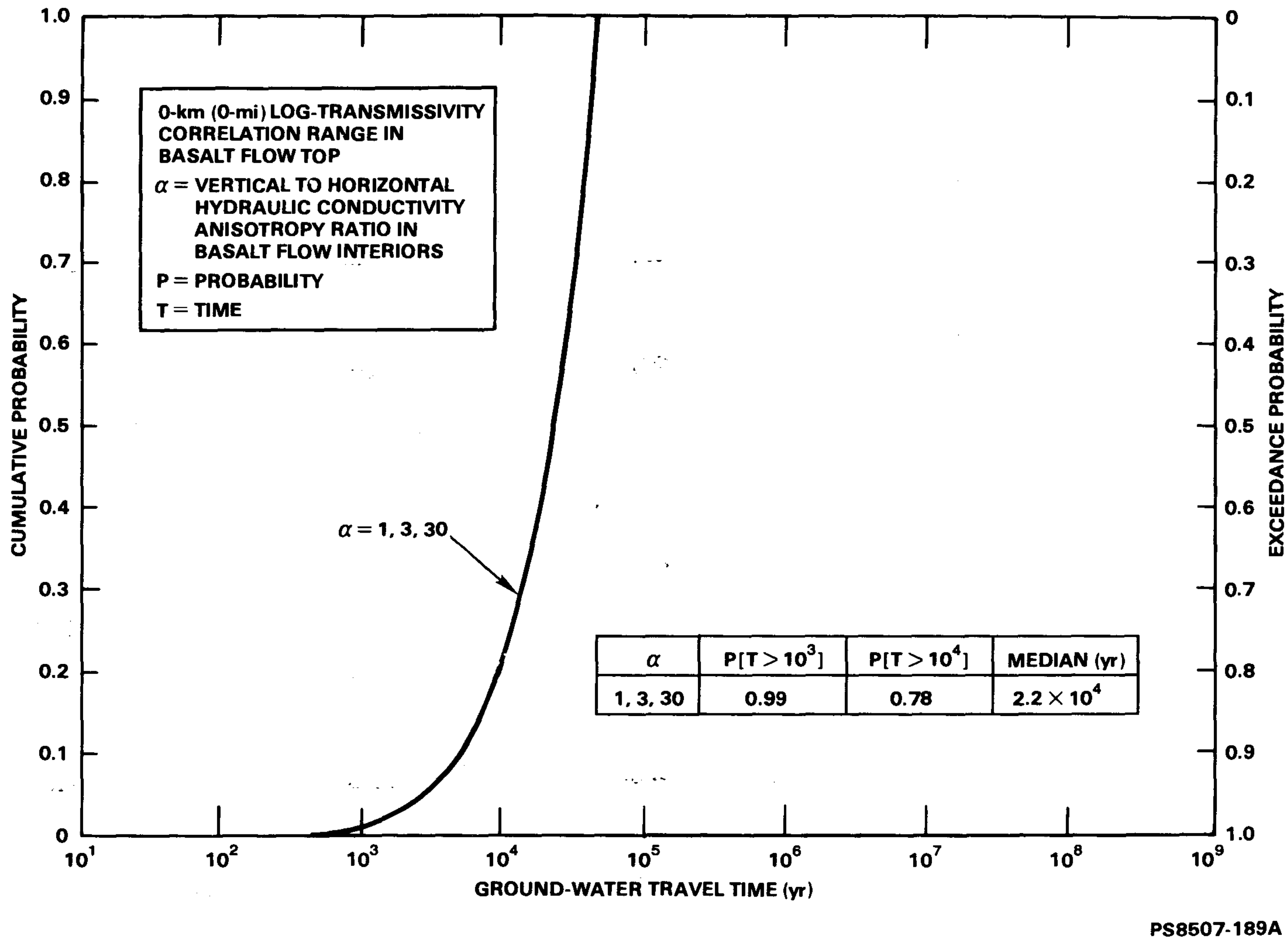
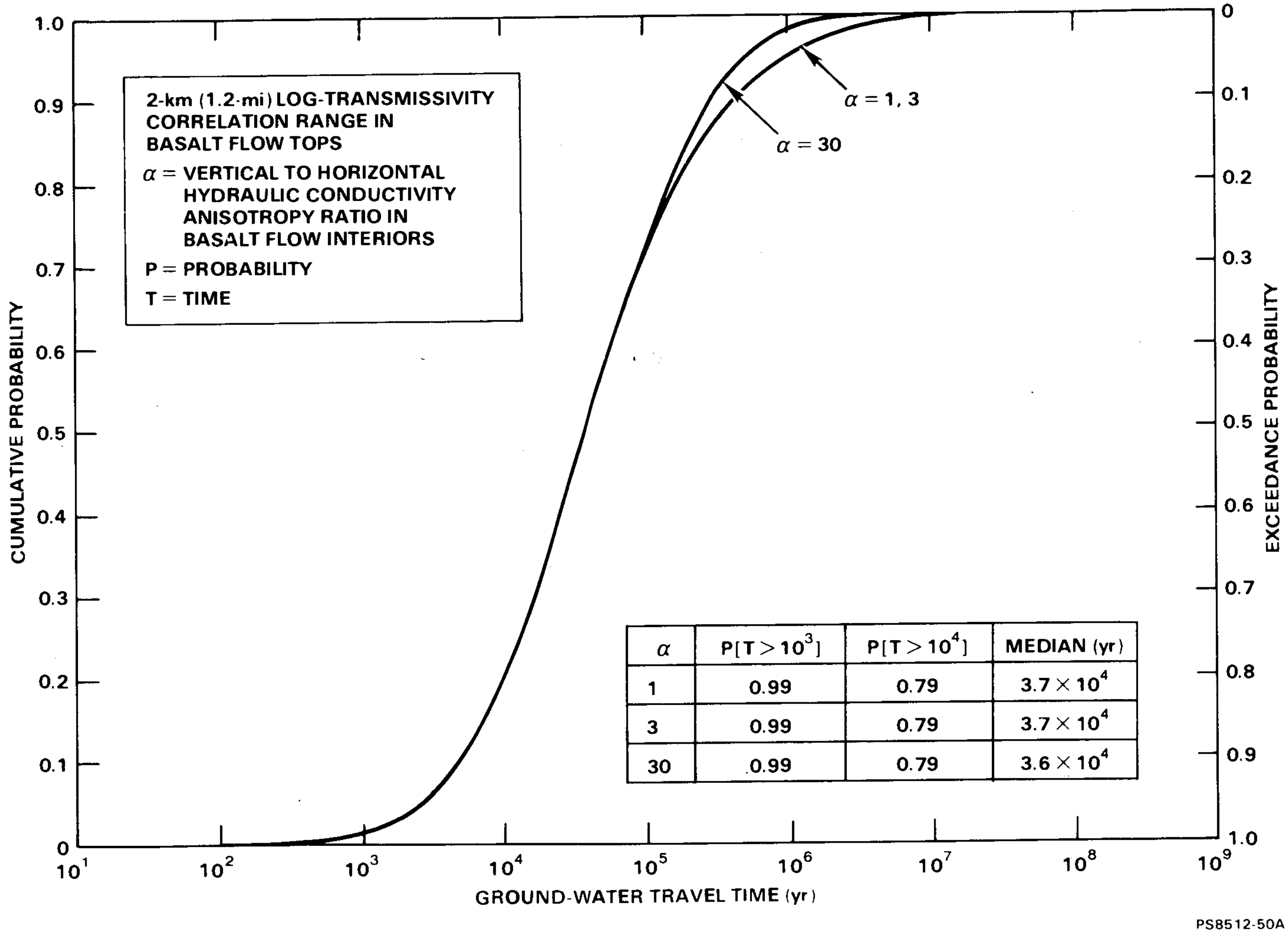
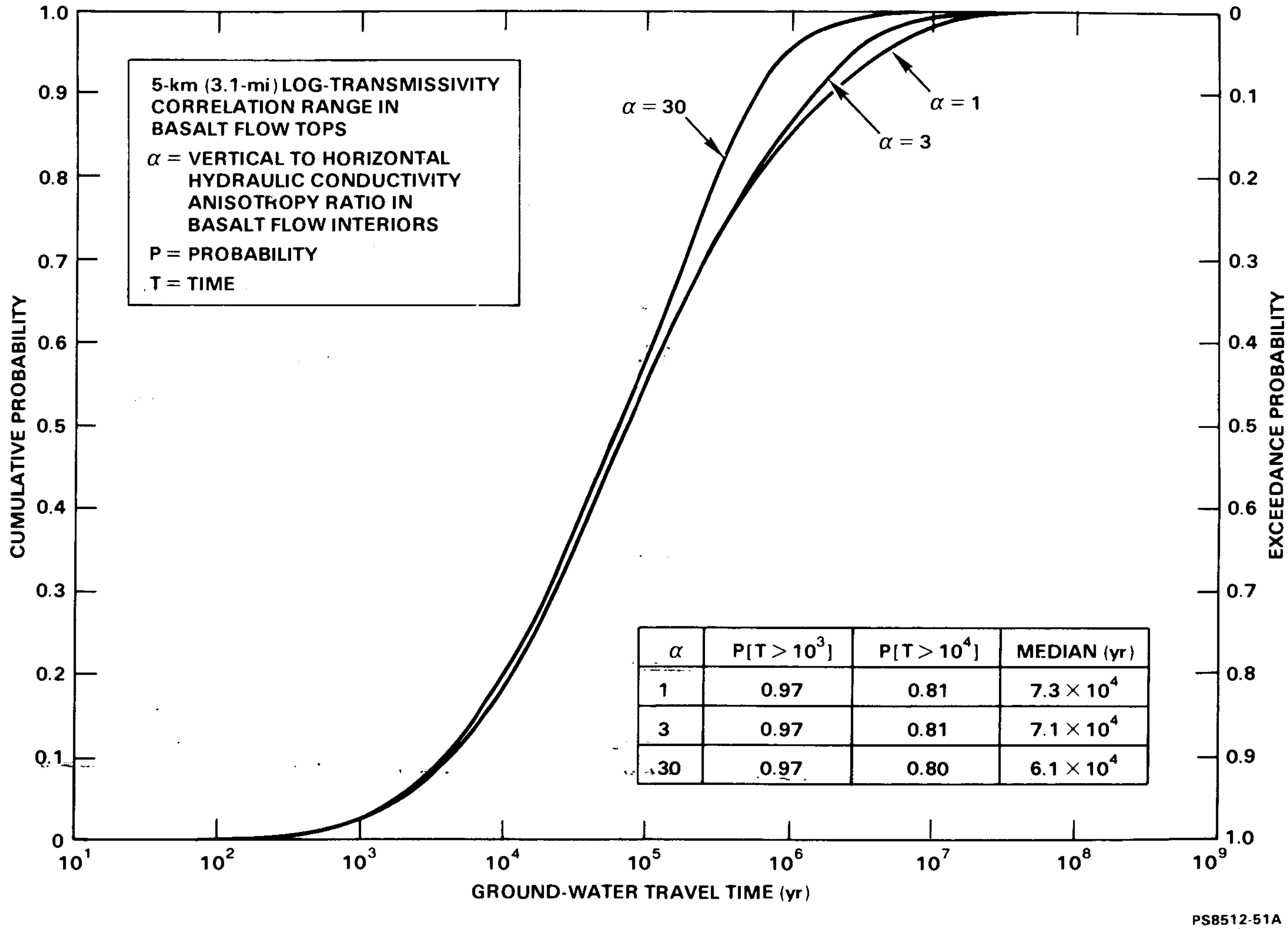


Figure 6-24. Probability distribution of ground-water travel times for 0-kilometer (0-mile) log-transmissivity correlation range, model 4.



α	$P[T > 10^3]$	$P[T > 10^4]$	MEDIAN (yr)
1	0.99	0.79	3.7×10^4
3	0.99	0.79	3.7×10^4
30	0.99	0.79	3.6×10^4

Figure 6-25. Probability distribution of ground-water travel times for 2-kilometer (1.2-mile) log-transmissivity correlation range, model 4.



α	$P[T > 10^3]$	$P[T > 10^4]$	MEDIAN (yr)
1	0.97	0.81	7.3×10^4
3	0.97	0.81	7.1×10^4
30	0.97	0.80	6.1×10^4

Figure 6-26. Probability distribution of ground-water travel times for 5-kilometer (3.1-mile) log-transmissivity correlation range, model 4.

system is refined, if the reference repository location were recommended for site characterization. Effort has been made in this ground-water travel-time study to make reasonable, conservative assumptions where necessary. It is likely that the above estimates of the exceedance probabilities for travel times of 1,000 and 10,000 years will increase as site characterization proceeds. Thus, the above exceedance probabilities are considered to be reasonable and conservative estimates, even though they are considered to be preliminary. Subsections 6.3.1.1.3 and 6.3.1.1.11 discuss the use of these results for evaluating the reference repository location according to the General Siting Guidelines (DOE, 1984a).

6.4.2.6.2 Cumulative radionuclide release

For the analysis of cumulative radionuclide release from the site subsystem (and, therefore, from the overall waste-isolation system), it was assumed that the waste packages were emplaced in the Cohassett flow interior. The release and transport processes were represented by a period of complete containment, followed by release at a constant rate derived from the results presented in Subsection 6.4.2.4, and finally by transport in ground water, with retardation by adsorption, to the accessible environment. For purposes of introducing conservatism, radionuclide containment by the zircaloy cladding and spent fuel matrix dissolution effects were neglected. The method, data, and results of this preliminary analysis are presented in the following subsections.

Modeling approach

The model utilized for probabilistic analysis of the system is designated EPASTAT (Eslinger and Sagar, 1986). The basic process considered is transport in ground water from a point source along a linear path without dispersion. Decay chains are not considered. Radionuclide travel times are computed as the product of a common input value of ground-water travel time and radionuclide-specific retardation factors. Release rate, following a stipulated containment period, can be defined either as a constant represented by the product of water flow rate and solubility (lasting until inventory depletion), or as a decaying annual rate lasting for a specified interval. All of the significant parameters are expressed as distributions, and a Monte Carlo sampling technique is utilized to select a vector (i.e., parameter set) for each trial. The computed performance measure for each trial is a summation of radionuclide cumulative fluxes, each normalized against an allowable limit, at a specified time (usually 10,000 years, because the analysis is generally utilized to assess compliance with the U.S. Environmental Protection Agency release standard (EPA, 1985)). The collection of results is automatically plotted in the form of a probability distribution function as shown in Figure 6-27; the ordinate value represents the probability that release to the accessible environment will be less than the abscissa value.

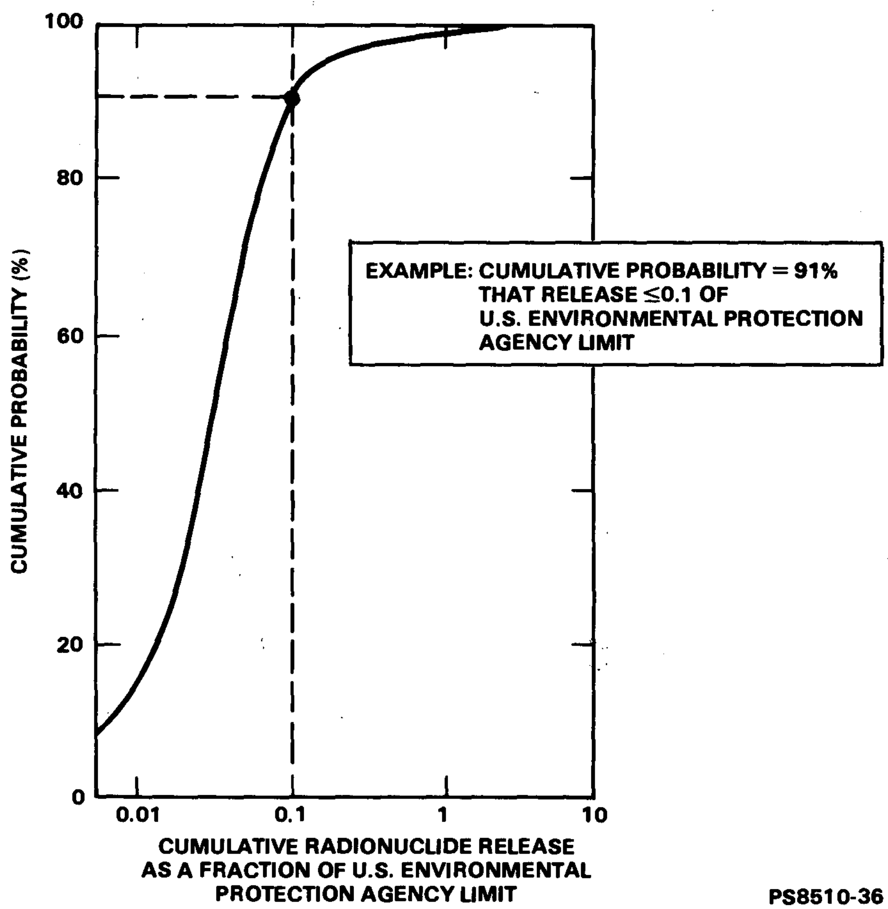


Figure 6-27. Hypothetical probability distribution function.

The assumption that decay chains have a negligible effect on release to the accessible environment was based on a preliminary analysis of radium-226 formation and transport that indicated the following:

1. The release rate for uranium-234, the principal precursor of radium-226, is low, thereby restricting most radium-226 formation to the vicinity of the repository.

2. The adsorptive properties and short half-life of radium-226 appear to ensure that it will not be transported significant distances from its point of origin in the repository.

The principal input and output parameters are shown in Table 6-33. The ground-water travel time distribution was obtained from the analysis discussed in the previous subsection and in Clifton (1986). Uncertain parameters were represented by probability distributions, and a Monte Carlo routine was used to select a data set for each simulation. The summation of values for the ratio of predicted release to allowable release provided a release term for each input vector. The release terms, when plotted in ascending order of release, display the fraction of samples for which release is less than a specified value.

Table 6-33. Principal input-output information for analysis of cumulative radionuclide release from the site subsystem

Input
Ground-water travel time
Water (solvent) flow rate
Radionuclide solubilities
Radionuclide-retardation factors
Radionuclide inventories
Time limit (usually 10,000 years)
Output
Probability curve for cumulative release (expressed in multiples of the U.S. Environmental Protection Agency allowable limit)

Data set for cumulative radionuclide-release analysis

The ground-water travel-time distribution used in EPASTAT (Fig. 6-28) approximates the collection of analytical results presented in Clifton (1986). Very long travel times tend to yield zero or low releases to the accessible environment, so the portion of Figure 6-28 important to EPASTAT is the short travel-time (lower left) portion of the curve.

The exceedance probabilities for 1,000- and 10,000-year travel times reported in Clifton (1986) were reasonably constant for all of the conceptual models at exceedance probability values of 97 percent (-1.88σ) and 78 percent (-0.77σ), respectively. Independence of these results from the particular conceptual model is a result of the fact that the shorter travel times obtained with any of the conceptual models represent those trials in which the flow path was totally within the flow top immediately above the Cohassett flow interior. This is convenient insofar as defining a travel-time input distribution for the EPASTAT analysis, because, with no vertical legs in the path, the pre-emplacement travel times reported in Clifton (1986) do not have to be adjusted for buoyant gradients induced by heat in the stored waste.

From the exceedance probabilities, and assuming that a lognormal travel-time distribution is a reasonable representation of the detailed analytical results for the purpose of estimating radionuclide releases,

$$\log M - 0.77\sigma = \log 10,000 = 4 \qquad (6\text{-}6)$$

$$\log M - 1.88\sigma = \log 1,000 = 3 \qquad (6\text{-}7)$$

where:

M = median travel time
σ = log standard deviation.

Solving for M and σ yields:

M = 49,400 years
σ = 0.90.

Because releases to the accessible environment, particularly in the first 10,000 years after repository closure, are dominated by the low end of the travel-time distribution, the selected representation is considered adequate for this preliminary analysis.

The release rate is computed in EPASTAT (Eslinger and Sagar, 1986) by a simple expression representing radionuclide solubility times solvent (water) flow rate:

$$\text{release rate} = mMSW \qquad (6\text{-}8)$$

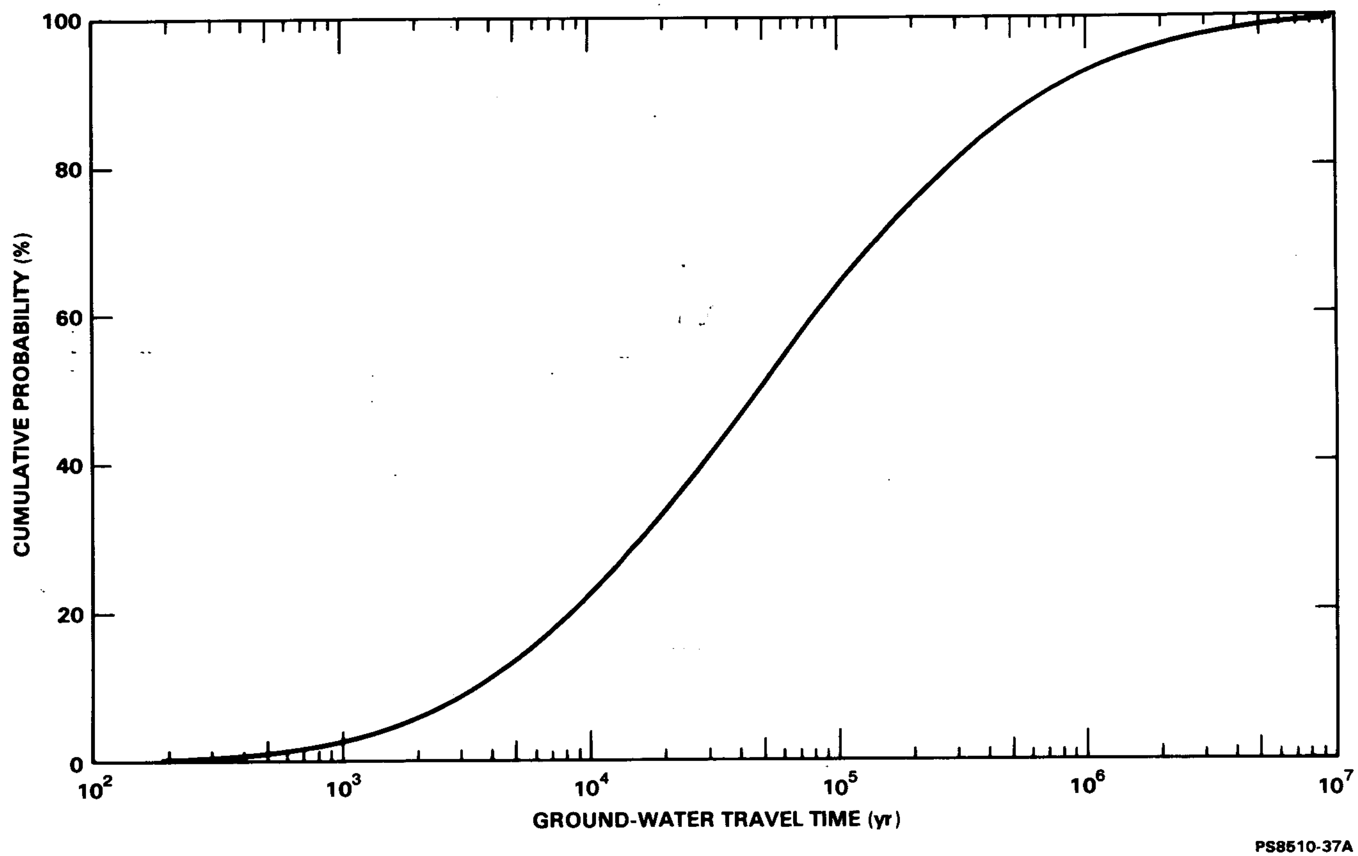


Figure 6-28. Ground-water travel-time distribution for cumulative release analysis.

where:

m = molecular weight, grams per mole
M = molar solubility, moles per liter
S = specific activity, curies per gram
W = water flow rate, liters per year.

The diffusionally controlled peak release rates listed in Table 6-27, however, are expressed as fraction per year of the inventory at 1,000 years after repository closure. Thus,

$$\text{release rate} = fI \qquad (6\text{-}9)$$

where:

f = fractional release rate, $year^{-1}$
I = radionuclide inventory, curies.

Based on Equations 6-8 and 6-9 for release rate, EPASTAT can match the estimated fractional release rates (see Table 6-27) for its source term by assigning unity as the water flow-rate value and by assigning each radionuclide an equivalent solubility equal to

$$M' = fI/mS \qquad (6\text{-}10)$$

where:

M' = equivalent saturation solubility, moles per liter.

For the performance limits case, values of M' were obtained by using the allowable release limits from Table 6-27 in place of the 90-percent probability uniform distribution values used in the reference case.

The release-rate characteristics presented in Subsection 6.4.2.7.1 represent the superposition of releases from individual containers that fail at different times. For simplicity and conservatism, the time-variant release rate for each radionuclide was characterized in EPASTAT as a constant release rate having the 90-percent probability peak value from the uniform distribution column of Table 6-27. Based on the starting point for the container failure profile shown in Figure 6-14, containment duration in the reference case was assumed to be a single value, 4,700 years. Thus, the complex source term analysis described in Subsection 6.4.2.7.1 is simply represented in EPASTAT by simultaneous loss of containment in all containers and release of each radionuclide at a constant rate governed by its solubility.

Retardation factors were estimated based on the range of distribution coefficient (K_d) values presented in Table 6-25. The ratio of pathway density (ρ) to porosity (Θ) for transforming K_d values into retardation factors by the relationship

$$R_i \approx \frac{\rho}{\Theta} K_d \qquad (6\text{-}11)$$

where:

R_i = retardation factor for a specific isotope

was assumed to be 50 for the conservative (low end of range) K_d and 500 for the expected K_d. The resulting range of retardation factors was assumed to be distributed uniformly in the cumulative release analysis.

<u>Results</u>

The stochastic simulations of site subsystem performance provide results for cumulative radionuclide release in the 10,000-year (nominal case) period following repository closure and for the 100,000-year period (extended case) following repository closure. Two approaches were considered.

- A reference case in which containment and release values were those estimated by subsystem analyses.

- A performance limits case in which container lifetime and fractional release rates were arbitrarily set at 300 years and the allowable limits defined in 10 CFR 60 (NRC, 1985a).

The analyses were based on the assumption that the Cohassett flow top is the principal flow path for transport of radionuclides to the accessible environment (and that radionuclides are released directly into the flow top).

The results of these stochastic simulations are presented in graphic form. The vertical axis of each graph is the cumulative probability, which expresses the level of certainty that the value of the radionuclide release is less than or equal to values on the horizontal axis. The horizontal axis of each graph consists of the possible range of radionuclide release in fractions of the U.S. Environmental Protection Agency limit (EPA, 1985).

The predicted results, shown in Figures 6-29 through 6-32, are dominated by the releases of nonadsorbed radionuclides (carbon-14 and iodine-129) for the portion of the probability domain in which release is not zero. Within the ranges of values expected for solubility, retardation coefficients, and ground-water travel time, adsorbed radionuclides are not likely to contribute significantly to cumulative releases.

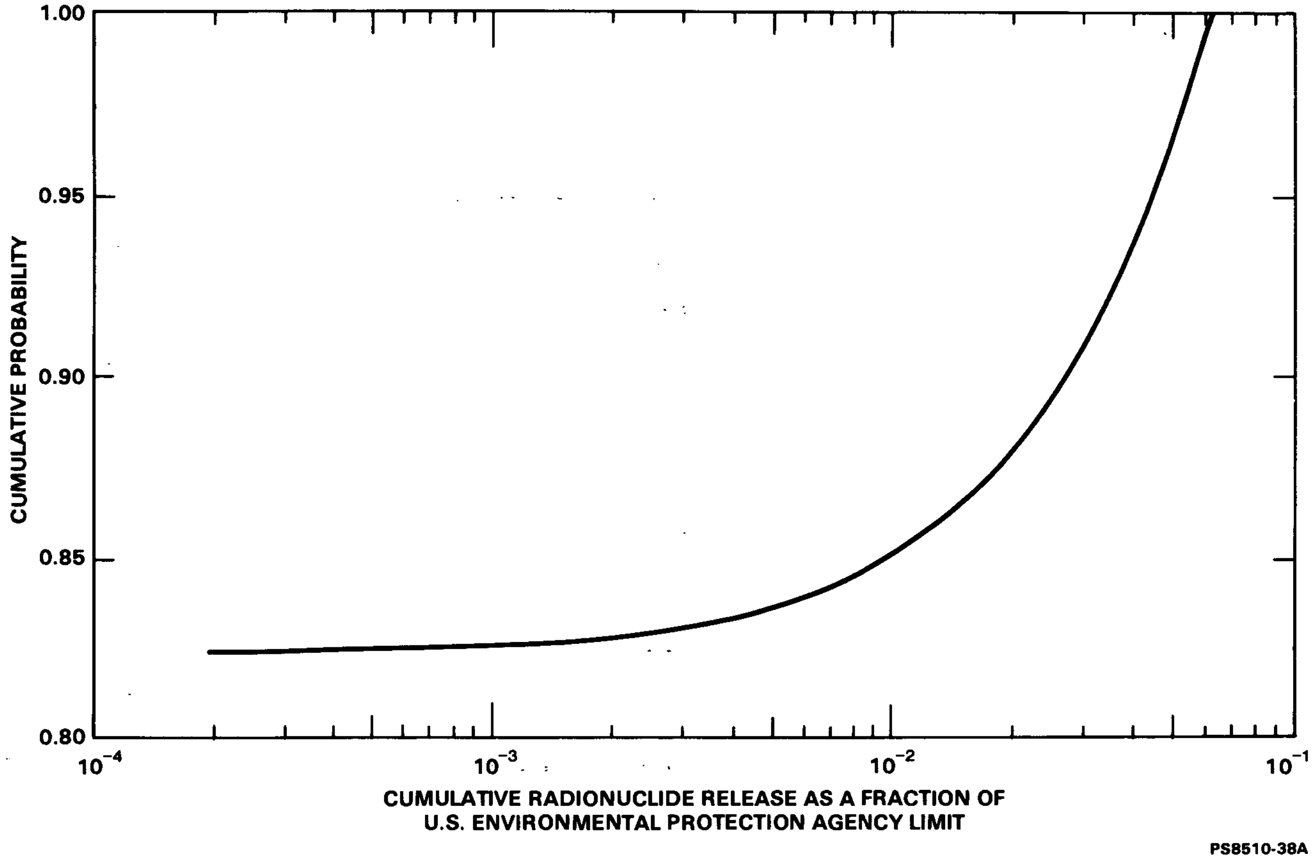


Figure 6-29. Cumulative radionuclide release during 10,000 years from the site subsystem to the accessible environment. Nominal reference case.

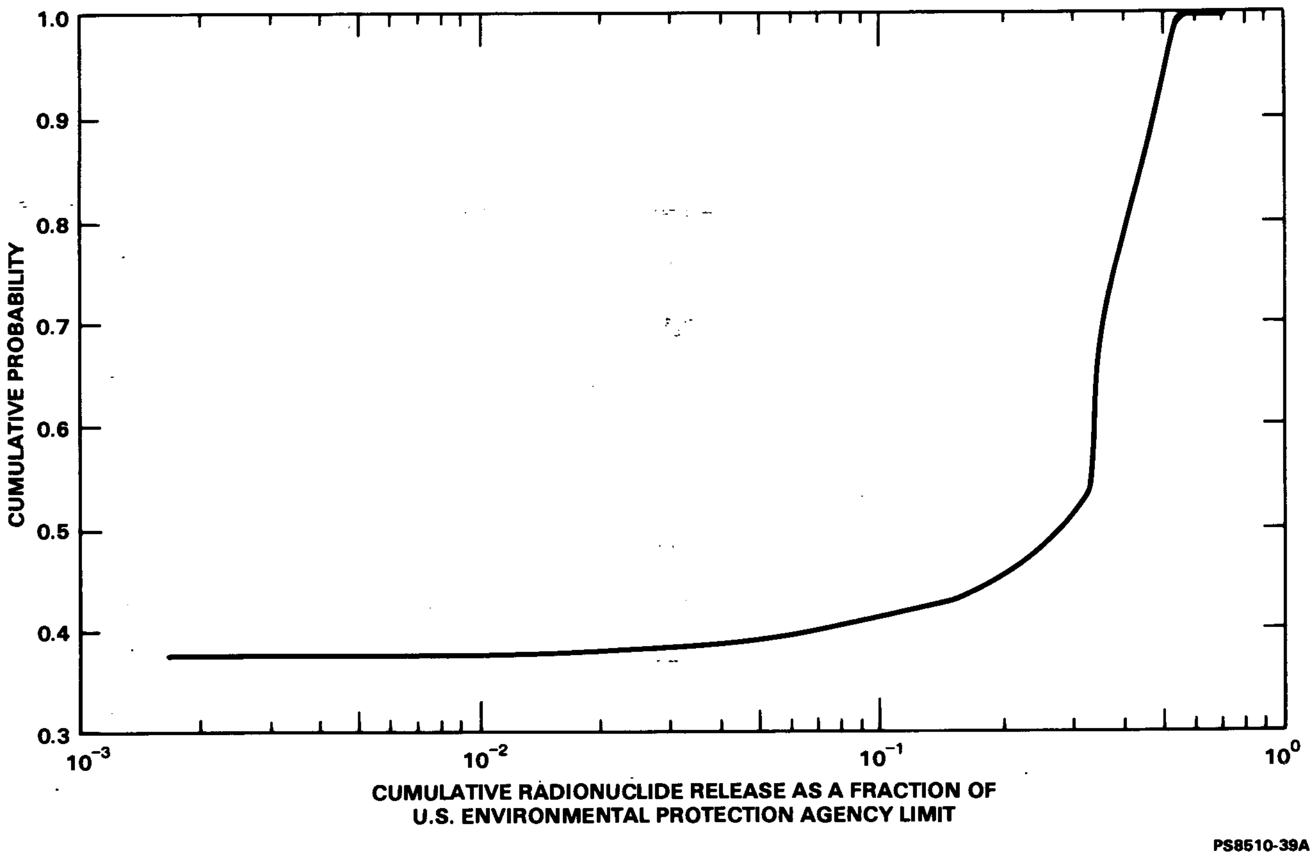


Figure 6-30. Cumulative radionuclide release during 100,000 years from the site subsystem to the accessible environment. Extended reference case.

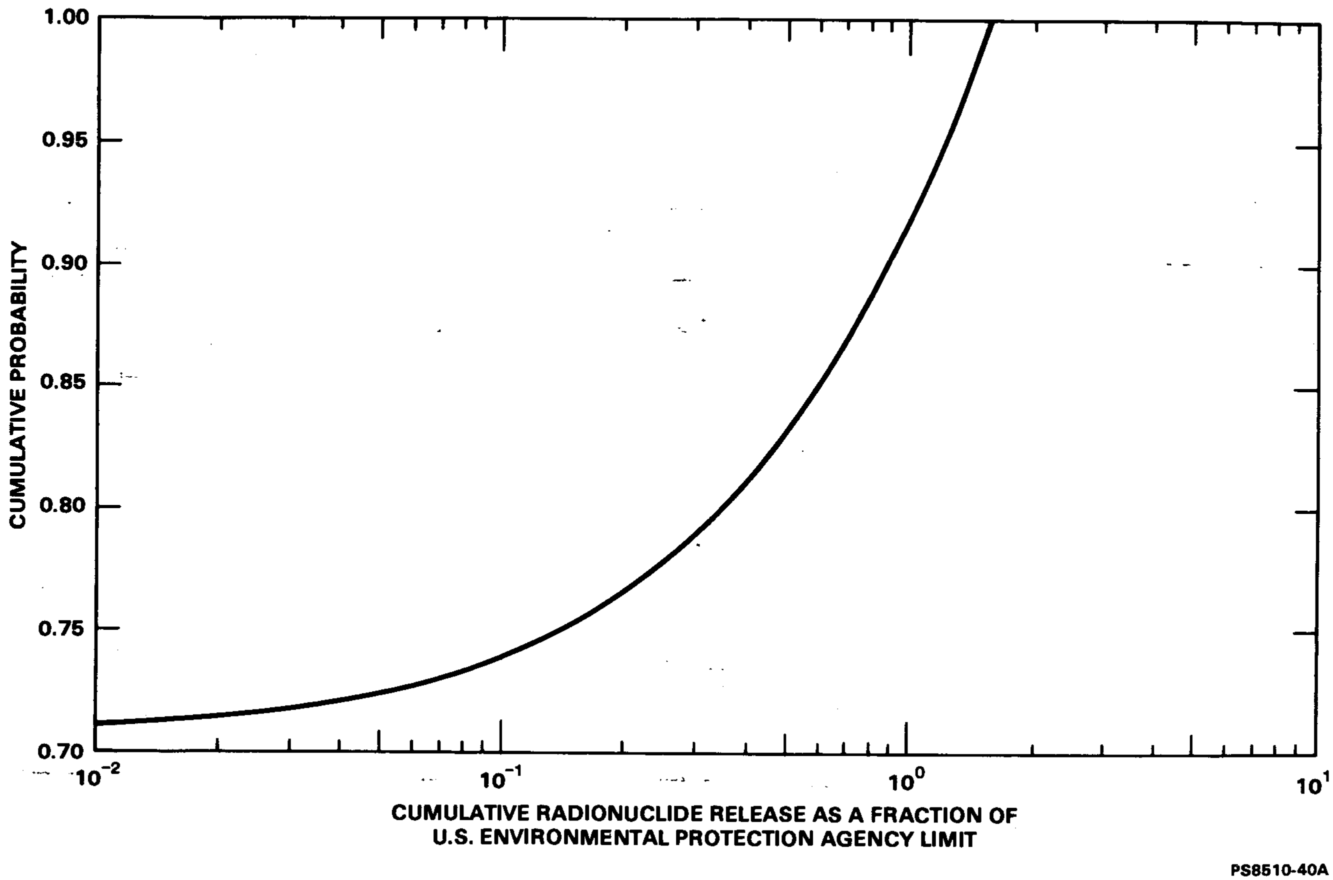


Figure 6-31. Cumulative radionuclide release during 10,000 years from the site subsystem to the accessible environment. Nominal performance limits case.

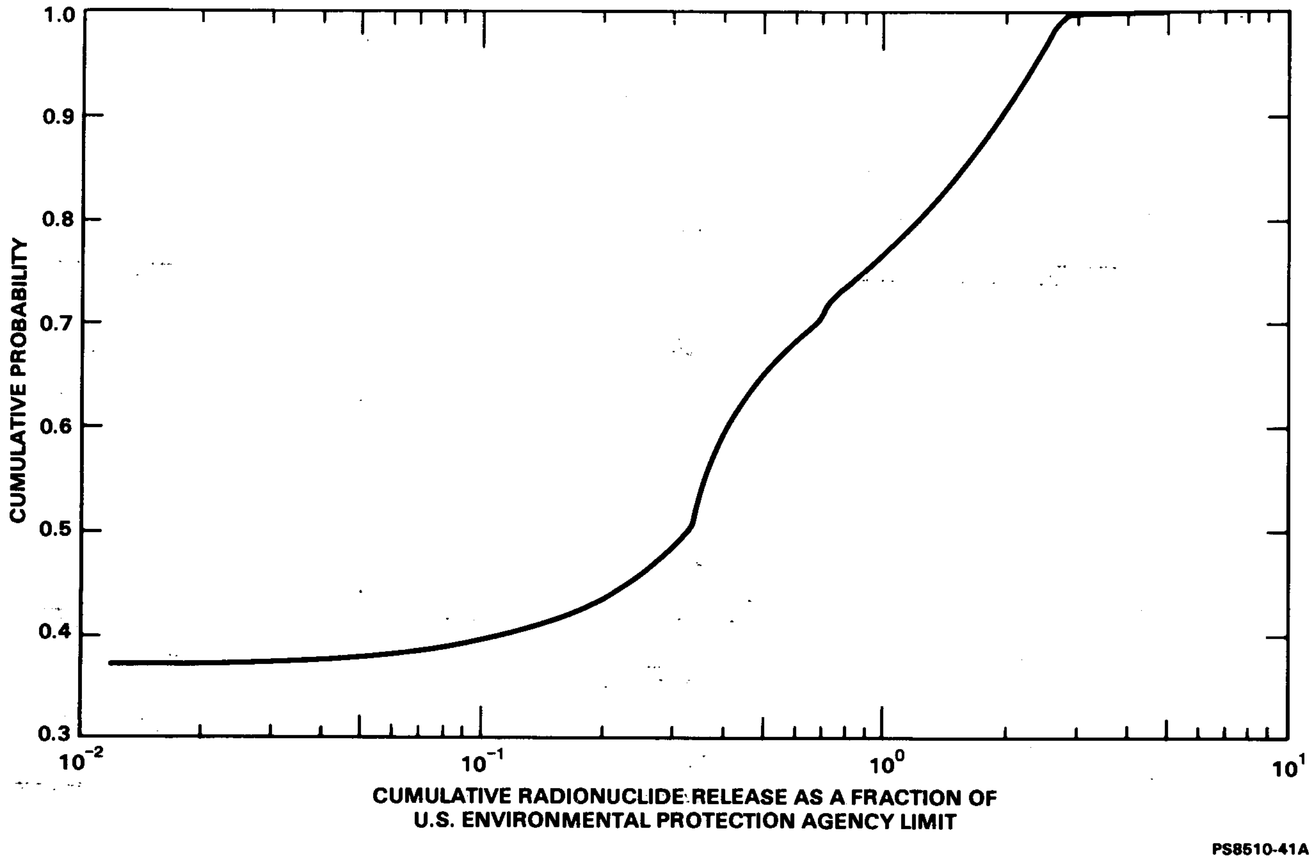


Figure 6-32. Cumulative radionuclide release during 100,000 years from the site subsystem to the accessible environment. Extended performance limits case.

The calculated cumulative radionuclide-release curves for a potential repository in basalt, as shown in Figures 6-29 through 6-32, share the following three basic features:

- A number of Monte Carlo trials computed radionuclide travel times that exceeded the isolation period (i.e., 10,000 or 100,000 years). For these trials, the cumulative releases are zero. The effect of long radionuclide travel times is reflected in the horizontal portion of the probability curves.

- The near-vertical portion of each curve shows the release of the total iodine-129 inventory.

- Adsorbed (and relatively insoluble) radionuclides are either totally absent from radionuclide release at the accessible environment or are evident in only a few of the 5,000 Monte Carlo simulations.

The analysis presented in this subsection provides useful insights into bounding conditions and sensitivities for isolation system behavior. This analysis must, however, be viewed in the context of its stated limitations to interpret the results properly. The representation of a physical system by a numerical model has two principal sources of uncertainty: (1) Simplistic (although thought conservative) representation of the actual physical system and (2) limited data. The computer code used in this analysis does not provide a detailed numerical representation of the complex hydrologic, chemical, and thermal processes involved in radionuclide transport. Instead, the inputs to the computer code are derived primarily from the outputs of other more-detailed models. The results of the analysis do, however, provide a good perspective on the potential isolation capability of the system and are believed to represent conservatively the potential isolation performance of the system.

6.4.2.7 Summary of performance assessment results

In the foregoing subsections, preliminary performance assessments were presented for a hypothetical repository in basalt. The assessment analyzed the performance of the three major subsystems (waste package, repository seal, and site) for a 10,000-year period after repository closure. A second assessment analyzed the performance of the total repository system for the first 100,000 years after closure. For these assessments, two cases were considered and compared: A reference case and a performance limits case. A summary of the principal performance assessment results is presented below.

6.4.2.7.1 Performance of the waste package subsystem

The analysis of the waste package subsystem examined the relationships between subsystem performance and its controlling processes. The performance of the waste package subsystem was expressed in terms of three basic measures: Container lifetime, maximum fractional radionuclide-release rate, and cumulative radionuclide release. The latter two performance measures were computed at the boundary of the waste package subsystem (i.e., outer edge of the packing material) with a simplified two-dimensional model. Physical and chemical processes accounted for in the analysis were uniform container corrosion, molecular diffusion, radionuclide adsorption, and radionuclide decay. Computer simulations of container corrosion and radionuclide migration were carried out using a probabilistic approach. Statistical representations (i.e., probability distributions) were used to account for uncertainties in data and model parameters.

The computer simulations of the cases considered for waste package subsystem performance revealed the following.

- The expected lifetime (i.e., depletion of corrosion allowance) of the carbon steel containers, if dominated by uniformly distributed corrosion, would be on the order of 6,100 years, with a standard deviation of approximately 600 years. Moreover, the probability of container lifetimes greater than 1,000 years is estimated to be in excess of 0.99.

- The computer simulations of radionuclide migration through the packing material indicate that fractional release rates for the significant radionuclides did not exceed the U.S. Nuclear Regulatory Commission (NRC, 1985a) fractional release-rate criterion. These simulations did not account for additional containment provided by the spent fuel cladding or container confinement provided during the time between depletion of the container-corrosion allowance and container failure. In addition, these predictions neglected adsorption effects in the host rock and on container-corrosion products.

- Of the radionuclides considered in this analysis, only five appear to have potential release rates within three orders of magnitude of their allowable limits: Carbon-14, iodine-129, selenium-79, technetium-99, and tin-126.

- The simulations also indicate that the cumulative release of all radionuclides during 10,000 years would be small. In particular, the results indicate a high probability (i.e., probability of greater than 0.90) that the cumulative release at the waste package subsystem boundary would be less than the U.S. Environmental Protection Agency limit (EPA, 1985). (The limit actually applies at the accessible environment boundary; i.e., 5 kilometers (3.1 miles) from the edge of the repository).

The preliminary performance assessment demonstrates that, although additional data and refinement of knowledge are needed, the isolation performance of the waste package subsystem can be analyzed in a systematic manner that accounts for uncertainties.

6.4.2.7.2 Performance of the repository seals subsystem

A performance analysis of the repository seals subsystem was conducted to assess potential cumulative radionuclide release and its dependence on the hydraulic properties of the subsystem. For simplicity and conservatism, the analysis was based on a conceptual model that assumed that 10 percent of contaminated ground-water flow migrated through the repository seals subsystem. The performance measure considered was the cumulative radionuclide release during a 10,000-year period. The release was calculated at a subsystem boundary designated as the point at which the shafts intersect the Vantage interbed. The release at this boundary was computed as a function of the container lifetime, waste package subsystem fractional release rates, and the rates of ground-water flow and radionuclide migration through the repository seals subsystem. The processes accounted for in the calculations were radionuclide transport by advection and radioactive decay and retardation of radionuclides by adsorption. The probabilistic approach considered uncertainties in data and model parameters and the effects of varying geochemical conditions.

The computer simulations of repository seals subsystem performance showed the following:

- The performance of the waste package subsystem controls the release of radionuclides that enter the repository seals subsystem. The calculation of cumulative release from this subsystem is a function of the hydraulic properties (i.e., permeability and effective porosity) of the damaged rock zone surrounding the excavated facility. Thus, studies are needed to provide increased confidence in the range of hydraulic properties for the damaged rock zone.

- A small, cumulative radionuclide release would occur at the assumed repository seal subsystem boundary (Vantage interbed) during a 10,000-year period. For the cases considered, there is a high probability (0.90) that the cumulative release would be less than 0.01 times the U.S. Environmental Protection Agency release limit (EPA, 1985) that applies at the accessible environment boundary. However, these results are strongly dependent on the assumed magnitude of the waste package release rate, the proportion of contaminated flow (Estey and Arnett, 1986) entering the repository seals, and the hydraulic properties of the damaged rock zone surrounding the sealed construction openings. For higher values of hydraulic conductivity, the damaged rock zone is not an effective barrier to radionuclide migration unless measures are taken to seal it.

The preliminary performance assessment of the repository seals subsystem indicates that this subsystem is unlikely to be a significant pathway for radionuclide migration. However, it also indicates that characterization of the hydraulic properties in the damaged rock zone and that analysis of contaminated flow patterns in the repository will be important in determining the type of sealing required for the damaged rock zone, the drifts, and the shafts.

6.4.2.7.3 Performance of the site subsystem

To examine the potential isolation capability of the site subsystem, an analysis was performed in which the potential cumulative releases (at the accessible environment boundary at 5 kilometers (3.1 miles)) were calculated, based on the probabilistic ground-water travel-time distributions discussed in Subsection 6.4.2.6.1 (Models 1 and 4). The principal ground-water pathways considered were along flow tops overlying the emplacement horizon. (The primary flow path would actually start at the waste package, be upward through the Cohassett flow interior, and then be horizontal along the Cohassett flow top.) A conservative representation of radionuclide releases from the waste package was used as the source term for the site subsystem model. However, credit was not taken in this analysis for the travel time in the flow interior of the repository horizon.

The probabilistic computer simulations of radionuclide transport through the site subsystem suggest the following:

- Cumulative radionuclide release calculated at the accessible environment boundary is small, with a high probability (i.e., greater than 0.95) of meeting the U.S. Environmental Protection Agency limit (EPA, 1985). Moreover, the Cohassett flow interior is likely to contribute significantly to the isolation performance of the site subsystem if the additional isolation potential of the flow interior were factored into performance analysis. The main reasons for this contribution would be the expected long ground-water travel time through the basalt flow interior and the retardation of adsorbed radionuclides by the host rock.

- Potential cumulative radionuclide release at the accessible environment boundary is dominated by carbon-14 and iodine-129. Dominance of cumulative release by these radionuclides is due to the lack of adsorption properties, unlike the other significant radionuclides.

Overall, this preliminary performance assessment for the site subsystem indicates that site characterization would need to emphasize those data-collection activities that are relevant to (1) definition of the most likely flow paths from the repository to the accessible environment, (2) determination of hydraulic properties (e.g., hydraulic conductivity and effective porosity) of the upper Grande Ronde Basalt, and (3) experimental measurement of pertinent solubility and adsorption properties of significant radionuclides.

6.4.2.7.4 Performance of the total isolation system

The long-term isolation performance of the total repository system ultimately depends on the combined performance of the engineered and natural barriers. To develop a quantitative perspective of the isolation capability of the total system, an analysis was conducted for two cases: A reference case and a performance limits case. These analyses were made for two periods: 10,000 and 100,000 years.

The principal results of the performance assessment for the total system are

- For the reference conditions, all of the cases simulated showed a cumulative radionuclide release that is less than the U.S. Environmental Protection Agency limit (EPA, 1985) in 10,000 and 100,000 years after closure.

- For the performance limits conditions, 94 percent of cases simulated for 10,000 years and 77 percent of cases simulated for 100,000 years had cumulative radionuclide releases that were less than the U.S. Environmental Protection Agency limit.

Therefore, it is expected that a repository at the reference repository location could be able to meet the U.S. Environmental Protection Agency standard for radionuclide releases to the accessible environment.

6.4.2.8 Human intrusion and disruptive events

Assessment of long-term repository performance also requires consideration of potential disruptions to nominal repository performance during the 10,000-year period specified by regulatory standards (NRC, 1985a; EPA, 1985). The term disruption scenario is here defined as postulated events, processes, and conditions of human-induced or natural origin that could adversely affect repository performance. The objective of ongoing scenario studies is to identify site-specific scenarios, to classify them according to probability categories, and to characterize them to a degree sufficient to permit assessment of their effect on repository performance.

6.4.2.8.1 Development of methodology

Several methods can be used to assess disruption scenarios, including systems analysis, event and (or) fault-tree analysis, geologic simulations, and a formal Delphi method of eliciting technical opinion. Because of the length of the required assessment period (10,000 years), incomplete understanding of the mechanics that may lead to disruption scenarios and of the geology of the reference repository location and vicinity, all of the techniques mentioned above incorporate technical judgment. The U.S. Department of Energy is in the process of reviewing and evaluating various methods to develop and implement a reasonable approach for selection, evaluation of probability of occurrence, and characterization of disruption scenarios.

Golder Associates developed a program plan (Golder, 1984) for disruption scenario analysis of a repository. The purpose of scenario methodology is listed below.

- Identify a well-defined set of events, processes, and (or) characteristics that are judged to affect the capability of the repository to isolate radionuclides as measured by the regulatory criteria.
- Combine the events, processes, and (or) characteristics identified into scenarios.
- Screen the scenarios based on judgmental evaluation of expected consequences and (or) likelihoods.
- Quantify consequences and conduct additional screening.
- Compile performance predictions into an assessment of isolation performance.

The methodology is an iterative process that includes an initial screening procedure and sensitivity analysis to identify the dominant uncertainties and scenarios. The iterative analysis process continues until it can be determined whether or not fractional and cumulative releases and radionuclide travel time meet the U.S. Environmental Protection Agency standard (EPA, 1985) and U.S. Nuclear Regulatory Commission criterion (NRC, 1985a).

As an initial step toward the study of disruption scenarios for the reference repository location (Davis et al., 1983), a Delphi survey was conducted to obtain consensus on the probability of scenario occurrence and consequence. This approach was applied to 45 potential disruption scenarios, including human-induced and natural occurrences, which were initially identified (Table 6-34). The 45 potential disruption scenarios were ranked according to likelihood of occurrence and relative adversity of consequence.

6.4.2.8.2 Human interference

The General Siting Guidelines (DOE, 1984a) specify that a repository site ". . . be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation." Specifically, the guidelines state:

> "The site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements . . ."

Table 6-34. Potential disruption scenarios identified by means of a Delphi survey (sheet 1 of 2)

Item no.	Description
1.	Undetected flow breccia of areal extent less than 10 square kilometers (2 square miles) that adversely affects ground-water travel times
2.	Undetected fault with movement periodicity greater than one per 10,000 years
3.	Premature shaft seal failure resulting from No. 2
4.	Undetected flow breccia of areal extent greater than 10 square kilometers (2 square miles) that adversely affects ground-water travel times
5.	Undetected fault with movement periodicity less than one per 10,000 years
6.	Premature shaft seal failure resulting from No. 5
7.	Undetected major fault within the site
8.	Estimation uncertainty of greater than one order of magnitude in hydraulic conductivity
9.	Estimation uncertainty of greater than one order of magnitude in radionuclide-rock partition coefficient
10.	Estimation uncertainty of greater than one order of magnitude in the state of fracturing of undisturbed rock
11.	Glaciation
12.	Volcanism
13.	Latent seismic activity triggered by changes in hydraulic pressure and rock stress
14.	Estimation uncertainty of greater than one order of magnitude in convective dispersion through fracture or interflow systems
15.	Fault movement with periodicity greater than one per 10,000 years that could intersect the repository
16.	Seismicity of less than 6.7 magnitude, with faulting
17.	Seismicity of greater than 6.7 magnitude, with faulting
18.	Celestial impacts
19.	Seismicity-induced failure of shaft seals due to faulting
20.	Ground-water chemistry changes with adverse effects on radionuclide flux
21.	Breach or premature failure due to net effects of surficial geologic processes
22.	Intrusive igneous activity
23.	Microseismicity with host rock fracturing
24.	Collapse of repository waste into undetected voids, such as lava tubes
25.	Diapirism of rock underlying repository host rock (e.g., shale, serpentine, evaporite)
26.	Change in transport properties causing a decrease of greater than 50 percent in ground-water travel times
27.	Premature failure or omission of engineered repository systems
28.	Latent seismicity triggered by changes in hydraulic pressure and rock stress as a result of repository heating
29.	Estimation errors of fracture permeability of greater than 50 percent due to conditions changed from testing environment

Table 6-34. Potential disruption scenarios identified by means of a Delphi survey (sheet 2 of 2)

Item no.	Description
30.	Breakdown of shaft seals by chemical and (or) mechanical aging
31.	Adverse effects on ground-water travel time due to adverse effects on recharge, because of severe changes in precipitation
32.	Adverse effects on ground-water travel time due to adverse effects on recharge, because of accelerated erosion or sedimentation
33.	Change in the course of the Columbia River that adversely affects the hydrologic system of the site
34.	Climatic change; development of glaciers and ice sheets in the region
35.	Adverse effects on ground-water travel time due to adverse effects on recharge, because of severe changes in the local water budget (i.e., evaporation and (or) precipitation ratio)
36.	Criticality; assumes unreprocessed spent fuel in storage
37.	Shaft seal failure due to methane, hydrogen, or steam explosions
38.	Premature failure or omission of waste package engineered systems
39.	Estimation uncertainty of greater than 50 percent in extent of host rock fracturing induced by radiogenic heat
40.	Estimation uncertainty of greater than 50 percent in extent of host rock fracturing induced by shaft, tunnel, and emplacement hole boring or mining
41.	Nuclear fuel recovery by deep mining methods
42.	Irrigation or other human-induced perturbation of the hydrologic system, resulting in adverse ground-water system perturbation
43.	Inadvertent entry by deep drilling
44.	A combination of human error during construction or decommissioning of the repository, together with natural disasters, (e.g., earthquake) that may possibly result in a permanent state of disrepair and radioactive release that would be excessively hazardous to remedy
45.	Breaching by nuclear weapons

NOTE: Davis et al. (1983).

Preliminary economic and geologic studies of the mineral, hydrocarbon (GG/GLA, 1981; Leaming and Davis, 1983), geothermal energy (Murphy and Johnpeer, 1981), and water resources (Leaming, 1981; Leonhart, 1980; Bell and Leonhart, 1980) potentially present at or near the reference repository location have been completed. These studies suggest that no natural resources (except for shallow ground-water supplies, sand, and gravel) are known or projected for the foreseeable future at the reference repository location that have a value sufficient to be considered commercially extractable (see Subsection 6.3.1.8). The mineral, hydrocarbon, and water-resource evaluations are based on published information on current and past resource production in the area, assessment of the likelihood of future discoveries based on the geologic setting, and economic analysis of the known and projected gross values, net values, and present values of the resources.

At the reference repository location the ground water in the Grande Ronde Basalt forms a series of generally low-permeability aquitards separating even lower permeability aquicludes (see Section 3.3.2). The deep ground water in Wanapum and Grande Ronde Basalts is not suitable for human consumption or crop irrigation without treatment (see Subsection 6.3.1.1.9). Natural gas in sufficient quantities to be economically extractable is at best speculative for the central Columbia Plateau. The reference repository location is situated in a structural low that is not expected to be a primary target for future natural gas exploration.

In view of the low resource potential of the reference repository location, the likelihood of human intrusion events (see Appendix B of 40 CFR 191 (EPA, 1985)) leading to releases exceeding the containment, individual protection, or ground-water protection requirements specified by the U.S. Environmental Protection Agency (EPA, 1985) is expected to be low.

Among additional published scenario studies, which are generic in nature or based on inference and extrapolation from sparse site-specific information, are Dove et al. (1981), A. D. Little, Inc. (1980), Hunter (1983b), and Lee et al. (1978).

Dove et al. (1981) demonstrated an application of a geologic, hydrologic, and geochemical simulation model, using input from technical opinion, to evaluate radionuclide releases from a repository resulting from disruption scenario conditions. The results are applicable only for one set of deterministically assigned parameters and one release scenario. The analysis did not consider a range of conditions and parameter values. This study was performed to demonstrate the use of a particular methodology and did not reach conclusions on isolation performance of a specific site.

A. D. Little, Inc. (1980) conducted an evaluation of 10 technology-related, human-intrusion, and naturally occurring disruption scenarios based on generic (non-site-specific) media characteristics. Occurrence probabilities and characterization of scenario parameters were deterministically assigned by A. D. Little, Inc., on a generic basis, rather than on the basis of site-specific information. Hence, the degree of uncertainty of a given parameter with respect to a specific site was not assessed. The findings presented in the report suggested that human-intrusion scenarios are likely to have low probabilities of occurrence, assuming that institutional control is maintained.

Hunter (1983b) evaluated the relative probabilities of occurrence of nine release phenomena for a hypothetical repository in Columbia River basalt by means of an event-tree analysis. Relative probabilities of scenario occurrence were subjectively assigned by Hunter, based on minimal site-specific information, and were used to screen selectively the scenarios for subsequent consequence analysis.

Lee et al. (1978) identified and described a list of disruption-initiating events that might affect a repository in basalt. The methodology used consisted of an event and fault-tree analysis for which occurrence probability estimates were developed for three trees. Ten human-penetration events were considered, six of which required loss of administrative control. Occurrence probabilities were subjectively assigned to such events on a deterministic basis. Participants in the analysis did not rank any human-intrusion event sufficiently high in occurrence to merit priority treatment in risk assessment.

Advantages and disadvantages are inherent in each of the several techniques thus far utilized for disruption scenario analysis. Assessment of their specific applications as reported in the above publications indicates that no single technique is capable of providing a comprehensive means of analysis. Consequently, it appears likely that a comprehensive methodology must be assembled from the various available techniques (Golder, 1984).

6.4.2.9 Preliminary performance assessment findings

In this subsection, the results of the subsystem and system performance assessments are compared with the criteria of the General Siting Guidelines (DOE, 1984a), 10 CFR 60 (NRC, 1985a), and 40 CFR 191 (EPA, 1985). The comparisons are not intended to demonstrate compliance with the guidelines, criteria, or standards. Rather, the results quantify the preliminary findings in a form that facilitates evaluation of the merits of further site characterization. The results are discussed in terms of the following criteria: Containment time, radionuclide release rate, ground-water travel time, ground-water protection, and cumulative radionuclide release.

6.4.2.9.1 Containment time

The U.S. Nuclear Regulatory Commission technical criteria, as specified in 10 CFR 60 (NRC, 1985a), set a containment time objective for the waste package. The technical criterion states:

"Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into "account the factors specified in 60.113(b) provided that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository."

A final determination of compliance with the containment time criterion cannot be made. Refinement of the technical understanding of the environmental factors controlling corrosion rates is needed. In addition, the understanding and the data on which corrosion rates are based must undergo detailed peer reviews by the U.S. Nuclear Regulatory Commission and other independent technical experts. The preliminary performance assessment of the waste package subsystem supports a preliminary finding that there is no evidence or indication that a 300- to 1,000-year containment period could not be achieved for the basalt environment by the current waste package design. The specific results of the preliminary performance assessment (see Subsection 6.4.2.4) suggest that the carbon steel containers could have expected lifetimes (i.e., time to deplete the corrosion-limit allowance) of approximately 6,100 years, with a standard deviation of approximately 600 years. The assessment results also suggest a high probability (i.e., greater than 0.99) of container lifetimes greater than 1,000 years.

The analysis of container lifetime is based on the assumption of uniformly distributed corrosion as the principal mechanism for container degradation. Conservatism was provided by defining the container lifetime as the time required to reach the corrosion-limit allowance and, therefore, not necessarily the time of actual container failure. In addition, credit was not taken for the added containment time potentially provided by zircaloy cladding of the spent fuel. Additional research will be needed to develop an understanding of other corrosion mechanisms (e.g., pitting) that potentially could reduce the container lifetime.

6.4.2.9.2 Radionuclide release rate

The U.S. Nuclear Regulatory Commission technical criteria, as stated in 10 CFR 60 (NRC, 1985a), established a radionuclide-release criterion for the waste packages that applies 1,000 years after permanent closure. The technical criterion specifically states:

"The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

A final determination of compliance with the release-rate criterion cannot be made. Additional experimental work is needed to reduce the uncertainty in estimates of radionuclide properties (e.g., solubilities, adsorption coefficients, and mass diffusivities) and to develop a better understanding of how the repository environment may affect these properties. In addition, the data and understanding produced by the experimental work must be peer reviewed by the U.S. Nuclear Regulatory Commission and other independent technical experts. The preliminary assessment of the waste package subsystem supports a preliminary finding that there is no evidence to suggest that the radionuclide release-rate criterion specified in 10 CFR 60 (NRC, 1985a) could not be met by the current waste package design. The results of the preliminary performance assessment (see Subsection 6.4.2.4) suggest that the fractional release rates calculated for the significant radionuclides are less than those allowed by the criterion. However, the release-rate calculations were performed for only those radionuclides that could potentially make significant contributions to cumulative release. Therefore, these calculations cannot be considered to be definitive.

The probabilistic computer calculations for cumulative releases (for all radionuclides analyzed) at the boundary of the waste package subsystem indicate a high probability (i.e., greater than 0.90) of meeting the U.S. Environmental Protection Agency limits, which apply at the boundary of the accessible environment (EPA, 1985). The preliminary analysis of waste package performance was conducted using data and assumptions that are considered to be of a conservative nature. However, additional research is needed to obtain data on radionuclide solubilities and to confirm estimates of adsorption and diffusion coefficients for the radionuclides of concern.

6.4.2.9.3 Ground-water travel time

The General Siting Guidelines (DOE, 1984a) and the U.S. Nuclear Regulatory Commission technical criteria (NRC, 1985a) specify pre-waste-emplacement ground-water travel time as a site performance measure. The applicable criteria in the General Siting Guidelines are given in Subsections 6.3.1.1.3 and 6.3.1.1.11.

The applicable criterion in 10 CFR 60 (NRC, 1985a) states:

> "The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission."

A precise definition of the disturbed zone has yet to be provided by the U.S. Nuclear Regulatory Commission. In the analyses presented in this environmental assessment, ground-water travel times are determined along pathlines starting at a point that is assumed to lie outside the disturbed zone. The boundary of the accessible environment is located 5 kilometers (3.1 miles) horizontally from the pathline starting point. All analyses of travel time to the accessible environment consider ground-water flow in one or more of the basalt flow tops overlying the Cohassett flow interior. These flow tops are considered to be pathways of likely and significant radionuclide travel following repository closure.

A final conclusion on the issue of compliance with the pre-waste-emplacement ground-water travel-time criteria cannot be made, based on the available hydrologic data and conceptual understanding of the deep ground-water flow system. The data and understanding needed to support a final conclusion can be obtained only through site characterization. Such information and resultant hydrologic interpretations must also be peer reviewed by the U.S. Nuclear Regulatory Commission and other independent technical experts. The preliminary determinations of ground-water travel time given in Subsection 6.4.2.6.1 support a finding that there is no evidence to indicate that the pre-waste-emplacement ground-water travel-time criteria in the General Siting Guidelines (DOE, 1984a) and 10 CFR 60 (NRC, 1985a) would not be met. These determinations of ground-water travel time indicate high likelihoods that travel time will exceed 1,000 and 10,000 years along pathways of likely and significant radionuclide travel. It should be noted that in the application of the travel-time criterion in 10 CFR 60, the U.S. Nuclear Regulatory Commission recognizes that a site may be acceptable according to this criterion, even though some of the predicted travel times may be less than 1,000 years (Browning, 1985).

Although this preliminary assessment of site performance indicates potentially long ground-water travel times, additional hydrologic field studies are needed to provide the data for validation of conceptual models used in the computer model predictions. Piezometric baseline studies and large-scale pumping tests are planned to provide greater insight into the hydrogeologic characteristics of the basalts and data on key hydraulic properties (e.g., hydraulic conductivities, gradients, effective porosities; see Section 4.1.1 and Subsection 6.3.1.1.11). These tests will be directed toward reducing uncertainties in computer model predictions. In addition to providing refined knowledge and understanding of the geohydrology, characterization activities would be directed toward quantitative definition of a preferred hydrologic conceptual model(s) for the reference repository location and vicinity.

6.4.2.9.4 Individual protection

The U.S. Environmental Protection Agency (EPA, 1985) sets a protection requirement for individuals in the accessible environment. The standard states:

> "Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways

"(associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside of the controlled area."

A final conclusion on whether or not the reference repository location complies with the individual protection requirement cannot be made at this time. It is unlikely that ground-water pathways in the deep basalts beneath the reference repository location or in the accessible environment would ever introduce hazardous amounts of radionuclides into any significant source of ground water as defined in 40 CFR 191 (EPA, 1985). Therefore, this question need not be addressed, because the approach to making a determination of compliance will be to design a waste package that has a high probability of containing the waste for 1,000 years. As indicated previously, the preliminary performance assessment of the waste package subsystem suggests that there is an expected container lifetime of greater than 1,000 years. Consequently, the assessment results of this report support a preliminary finding that it is unlikely the individual protection requirement would not be met.

6.4.2.9.5 Ground-water protection

The U.S. Environmental Protection Agency standard (EPA, 1985) sets a protection requirement for any special source of ground water. The standard states, in part:

"Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed: (1) 5 picocuries per liter of radium-226 and radium-228; (2) 15 picocuries per liter of alpha-emitting radionuclides; and (3) the combined concentrations of radionuclides . . . that would produce an annual dose . . . greater than 4 millirem per year if an individual consumed 2 liters per day of drinking water from such a source of ground water . . ."

A final conclusion on whether or not the reference repository location complies with the ground-water protection requirement cannot be made at this time. Although it is unlikely that ground water in the deep basalts beneath the reference repository location would be judged to be a special source of ground water under 40 CFR 191 (EPA, 1985), this question need not be addressed, because the approach to making a determination of compliance will be to design a waste package that has a high probability of containing the waste for 1,000 years. As indicated previously, the preliminary performance assessment of the waste package subsystem suggests that there is an expected container lifetime of greater than 1,000 years. Consequently, the assessment results of this report support a preliminary finding that it is unlikely the ground-water protection requirement would not be met.

6.4.2.9.6 Cumulative radionuclide release

The U.S. Environmental Protection Agency is responsible for setting radiological protection standards. The standard for mined geologic repositories (EPA, 1985) sets numerical limits on potential releases to the accessible environment. The standard states:

> "Disposal systems for spent nuclear fuel or high-level or transuranic wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of waste to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall: (1) have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1, and (2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1."

The first item requires that there be at least a 0.90 probability that the cumulative release be less than the release limit; whereas, the second part requires that there be at least a 0.999 probability that the cumulative release be less than 10 times the proposed release limit.

A final conclusion on the question of compliance with the U.S. Environmental Protection Agency cumulative release requirement cannot be made. A final conclusion can be made only after site characterization has been conducted. In addition, the data collected and knowledge gained from such a program would have to be peer reviewed by independent technical experts, the U.S. Nuclear Regulatory Commission, and other agencies. The preliminary performance assessment conducted supports a preliminary finding that it is unlikely the cumulative release requirement could not be met.

More specifically, the results of the preliminary performance assessment indicate that each of the major repository subsystems (i.e., waste package, repository seals, and site) could meet the cumulative release requirements. This means that the combined performance of the subsystems would have a higher probability of meeting the requirement than do each of the subsystems alone. This result was indicated in the assessment results for the total isolation system for the 10,000- and 100,000-year periods.

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Chapter 7

COMPARATIVE EVALUATION OF NOMINATED SITES

7.1 INTRODUCTION

7.1.1 PURPOSE AND REQUIREMENTS

This chapter presents a comparative evaluation of the five sites nominated as suitable for site characterization: Davis Canyon, Deaf Smith County, Hanford, Richton Dome, and Yucca Mountain (see Figure 7-1). Each site is a preferred site within a geohydrologic setting: Davis Canyon is in the bedded salt of the Paradox Basin in Utah; Deaf Smith County is in the bedded salt of the Permian Basin in Texas; Hanford is in basalt in the Columbia Plateau in Washington; Richton is a salt dome in Mississippi; and Yucca Mountain is in tuff in the Southern Great Basin in Nevada. The process that led to the identification of these sites is described in Chapter 2.

The major objective of this chapter is to present a comparative evaluation of the sites proposed for nomination in order to satisfy the following requirements:

1. Section 112(b)(E)(iv) of the Nuclear Waste Policy Act of 1982 (the Act), which requires that a "reasonable comparative evaluation" be included in the environmental assessments that accompany site nomination.

2. Section 960.3-2-2-3 of DOE's siting guidelines (10 CFR Part 960), which requires that a reasonable comparative evaluation be made and that a summary of evaluations with respect to the qualifying condition for each guideline be provided to "allow comparisons to be made among sites on the basis of each guideline."

This comparative evaluation is intended to facilitate the comparison of the more-detailed suitability evaluations reported for each site in Chapter 6. The comparison should assist the reader in understanding the basis for the nomination of five sites as suitable for characterization (Section 112(b)(1)(A) of the Act); it is not intended to directly support the subsequent recommendation of three sites for characterization as candidate sites.

7.1.2 APPROACH AND ORGANIZATION

This comparative evaluation of the five nominated sites is based on the postclosure and the preclosure guidelines (10 CFR Part 960, Subparts B and C, respectively). The reader is referred to Chapter 6 for a detailed discussion of the structure and the content of the siting guidelines. The evaluation presented in this chapter includes both the system guidelines and the technical guidelines.

Figure 7-1. Sites selected for nomination.

The comparison of the sites against each technical guideline uses the information from the guideline evaluations presented in Chapter 6 of the five environmental assessments, whereas the comparisons against the system guidelines summarize directly the evaluations reported in Chapter 6. The approach used to compare the sites against each technical guideline is summarized below.

In order to facilitate the comparison of sites on the basis of each qualifying condition, major considerations were derived by identifying the favorable, potentially adverse, and disqualifying conditions that deal with the same general topic. Contributing factors representing site characteristics that are potentially important to each major consideration were also identified. The relative importance of the major considerations was determined primarily by the degree to which they contribute to the qualifying condition; that is, the stronger the tie between the consideration and the qualifying condition, the greater the importance of the consideration. Each site was evaluated in terms of each major consideration, taking into account the contributing factors at that site.

The purpose of identifying major considerations for each guideline is to combine closely related site conditions so that the favorable and potentially adverse conditions can be considered on balance. A major consideration may be broader in scope than the combined scope of the related favorable and potentially adverse conditions, in order for it to relate more directly to the qualifying condition. Most guidelines that contain a disqualifying condition have one or more potentially adverse conditions that are related to the disqualifying condition. Since these potentially adverse conditions are considered in the formulation of a major consideration, the important aspects of the disqualifying conditions indirectly enter the comparative evaluation. Where a major consideration that is needed to evaluate the qualifying condition does not have a related favorable or potentially adverse condition, the consideration is derived directly from the qualifying or disqualifying condition. Not all contributing factors are discussed for each site; for brevity, only the factors that contribute to the evaluation of that consideration are discussed. The evaluation of each site with respect to each major consideration is presented in alphabetical order, by site.

The major considerations for the guidelines were then considered collectively, taking into account their relative importance, in a comparative evaluation of the sites. This comparative evaluation describes the sites with the most favorable combination of characteristics first and those with a less favorable combination of characteristics last.

The comparative evaluations of the sites are summarized in Sections 7.2 and 7.3 for the postclosure and the preclosure guidelines, respectively.

7.2 COMPARISON OF THE SITES ON THE BASIS OF THE POSTCLOSURE GUIDELINES

The postclosure guidelines are concerned with the characteristics, processes, and events that may affect the performance of the repository after closure. The objective is to ensure that the health and safety of the public will be protected for thousands of years, until the radioactivity of the waste has diminished to safe levels. This section presents a comparative evaluation of the five nominated sites against the postclosure guidelines.

7.2.1 TECHNICAL GUIDELINES

7.2.1.1 Geohydrology (postclosure)

The qualifying condition for geohydrology is as follows:

> The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in 10 CFR 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the favorable and potentially adverse conditions for this guideline, four major considerations (see Table 7-1) are identified that influence the favorability of the site with respect to the qualifying condition. These major considerations, in decreasing order of importance, are (1) ground-water travel time and flux, (2) changes in geohydrologic processes and conditions, (3) ease of characterization and modeling, and (4) presence of suitable ground-water sources. These major considerations are, in turn, influenced by a number of more specific geologic and hydrologic properties and in situ conditions called contributing factors.

Evaluation of the sites with respect to major considerations

Ground-water travel time and flux. This consideration covers the geohydrologic conditions that control the time of ground-water travel between the disturbed zone and the accessible environment and the ground-water flux (volumetric flow rate) across or through the repository and through the host rock to the accessible environment. It is related directly to the qualifying condition as a measure of the amount of ground water that can come in contact with the waste, the amount of ground water available to transport radionuclides between the repository and the accessible environment, the time delay for these radionuclides to reach the accessible environment, and the time available for radioactive decay during transport. This major consideration is derived from the first, fourth, and fifth favorable conditions of the geohydrology guideline. It is the most important of the major considerations because transport by ground water is the primary mechanism for radionuclide movement from the repository to the accessible environment.

The contributing factors for this consideration include the hydraulic conductivity and gradient, the effective porosity, the degree of saturation, the depth to the water table, the presence of flow through fractures or porous

Table 7-1. Guideline-condition findings by major consideration—geohydrology[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: GROUND-WATER TRAVEL TIME AND FLUX					
Favorable condition 1					
Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.	P	P	P	P	P
Favorable condition 4					
For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:	P	P	P	NP	NA
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.	P	P	NP	NP	NA
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.	NP	P	NP	NP	NA
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.	NP	NP	P	NP	NA
(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.	NP	NP	NP	NP	NA
Favorable condition 5					
For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:	NA	NA	NA	NA	P
(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.	NA	NA	NA	NA	NP
(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.	NA	NA	NA	NA	P
(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.	NA	NA	NA	NA	NP
(iv) A host rock that provides for free drainage.	NA	NA	NA	NA	P
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.	NA	NA	NA	NA	P

Table 7-1. Guideline-condition findings by major consideration—geohydrology[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: CHANGES IN GEOHYDROLOGIC PROCESSES AND CONDITIONS					
Favorable condition 2					
The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	P	P	P	P	NP
Potentially adverse condition 1					
Expected changes in geohydrologic conditions--such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units—sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: EASE OF CHARACTERIZING AND MODELING					
Favorable condition 3					
Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
The presence in the geologic setting of stratigraphic or structural features--such as dikes, sills, faults, shear zones, folds, dissolution effects, or bring pockets—if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.	P	P	P	P	P
MAJOR CONSIDERATION 4: PRESENCE OF SUITABLE GROUND-WATER SOURCES					
Potentially adverse condition 2					
The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water-flow paths from the host rock to the accessible environment.	NP	NP	NP	NP	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

media, net infiltration, the extent of the disturbed zone, and the distance to the accessible environment.

At each of the sites there are uncertainties in the conceptual model of ground-water flow, including the values of the key hydraulic parameters that control ground-water travel time and flux. Taking the uncertainties into account, there are ranges of possible travel times between the disturbed zone and the accessible environment at each site. Therefore, ground-water travel time was stochastically modeled at each site, using reasonably conservative geohydrologic assumptions and ranges of hydraulic parameters. Probabilistic ranges in travel time and the statistical probability for exceeding travel times of 1,000 and 10,000 years were derived for each site. In general, the ground-water flux is expected to be low to very low at each of the sites. A summary of the evaluation for each site follows.

At Davis Canyon, ground-water travel times from the disturbed zone to the accessible environment are modeled as porous-media flow vertically and horizontally through a layered sequence of differing lithologies (salts, anhydrite, dolomite, siltstone, etc.). The calculated travel times depend on the hydraulic conductivity and the effective porosities of the varying lithologies, the thickness and continuity of each layer, and the vertical and horizontal hydraulic gradients within and between each layer. Because the values of these parameters are uncertain, the expected ground-water pathways are uncertain. To quantify this uncertainty at Davis Canyon, a computer code was developed to evaluate the probability the distribution of travel times based on distribution of hydrologic parameters derived from data collected at a DOE test well (Gibson Dome No. 1) 5 kilometers (3 miles) north of the site, various oil test wells in the Paradox Basin, and various published sources of generic data. For purposes of analyzing the ground-water travel time, the outer edge of the disturbed zone was conservatively assumed to be at the top and bottom of the host salt bed, because of uncertainty in the extent of the disturbed zone. The time required for ground water to travel through the host salt bed is not included in the calculations of pre-waste-emplacement travel time to the accessible environment. The overall regional vertical hydraulic gradient between the upper and the lower hydrostratigraphic units, separated by the evaporite section containing the host salt bed, is generally downward. However, data collected at the Gibson Dome test well indicate both local downward and upward gradients between interbeds in the evaporite section containing the proposed host salt bed. The combined vertical and horizontal gradients in the area then result in either upward-to-lateral flow or downward-to-lateral flow within the layered sequence. Both the upward-to-lateral and downward-to-lateral travel times are analyzed, resulting in quite similar distributions.

The proposed controlled-area boundary for the Davis Canyon site is limited to a distance of 1 kilometer (0.6 mile) from the edge of the disturbed zone to the accessible environment due to the proximity of Canyonlands National Park in the expected direction of ground-water flow. For a lateral distance of 1 kilometer (0.6 mile) from the outer edge of the disturbed zone to the accessible environment, downward-to-lateral travel times were stochastically analyzed through 1,000 realizations of the model. This results in a probability of .003 for travel times of less than 1,000 years and probability of a .045 for less than 10,000 years. The median travel time is 240,000 years. A distance of 5 kilometers from the edge of the repository was also analyzed in case the boundary of the controlled area should change as a result of data developed during site characterization in a direction away from the Canyonlands National Park. This analysis results in a probability of less than 0.001 for travel times of less than 1,000 years and .006 for less than 10,000 years, with a median travel time of 880,000 years.

The Deaf Smith site is in a geohydrologic setting that is conceptually similar to that of the Davis Canyon site. A similar stochastic analysis of pre-waste-emplacement ground-water travel time was made. The computer flow model, as for Davis Canyon, consists of a series of layers representing a sequence of differing lithologies (salt, anhydrite, dolomite, siltstone, etc.), including the host salt bed. Only downward-to-lateral travel times were calculated, because only downward vertical hydraulic gradients have been observed in the vicinity of the site. The travel time was calculated beginning at the bottom of the salt repository bed (considered conservatively as the bottom edge of the disturbed zone) and extending 1 kilometer to the accessible environment. To consider the possibility that the boundary of the controlled area (and the distance to the accessible environment) might be extended, travel times were also calculated to the maximum 5-kilometer distance from the edge of the disturbed zone. The modeling is based on data obtained from literature reviews, analyses of water-well and petroleum-well records and pump testing, analyses of drill-stem tests, and analyses of laboratory tests conducted specifically for the repository program. There is a comparable level of uncertainty in the data bases for the Deaf Smith and the Davis Canyon sites. Considering porous-media flow as the likely flow mechanism, the results of travel-time analyses for an accessible environment 1 kilometer from the edge of the disturbed zone, on the basis of 1,000 realizations of the model, show a probability of .005 for travel times of less than 1,000 years and a probability of .107 for less than 10,000 years, with a median travel time of 87,000 years. For an accessible environment 5 kilometers from the edge of the disturbed zone, the probability of travel times of less than 1,000 years is less than .001, and the probability for less than 10,000 years is .015, with a median travel time of 500,000 years.

At the Hanford site, the stochastic analysis of the pre-waste-emplacement ground-water travel time used a conceptual model that is consistent with the current understanding of the deep ground-water flow system and considers the uncertainties in the hydraulic parameters used to predict travel times. In the analysis, ground-water flow is modeled along upward and lateral flow paths through an alternating sequence of basalt flows in which dense interiors of low permeability are separated by flow tops of higher permeability. The vertical and horizontal hydraulic-head gradients used in the stochastic model are deterministic; that is, they are based on quality head data obtained from piezometers at the site. The transmissivity values used in the model were based on site-specific test data that were varied over a reasonably conservative range. The range of effective porosity was estimated from geophysical logs, core samples, two tracer tests, and values reported in the literature. Key hydraulic parameters were conservatively evaluated over appreciable ranges in the model. The model considers ground-water movement that begins in the flow top immediately above the dense flow interior (the outer edge of the disturbed zone being within the dense interior host rock at an unknown distance from the flow top) of the proposed host rock and proceeds vertically upward and laterally to the accessible environment, 5 kilometers from the edge of the repository. The model conservatively does not include vertical travel time through the upper part of the undisturbed dense interior between the proposed repository and the base of the first flow top above the repository. The range of travel times derived from the model indicates a probability of .03 or less for travel times of less than 1,000 years and a probability of .22 or less for travel times of less than 10,000 years. This compares with the shortest median travel time for the conservative analyses of 22,000 years.

At the Richton site, the accessible environment is considered to be at the flank, or periphery, of the salt stock; therefore, ground-water travel times from the disturbed zone to the accessible environment (a minimum lateral distance of 244 meters (800 feet)) are judged to be within essentially pure salt. The mechanism for ground-water movement through the salt is uncertain. Because of the ductility of salt, which reduces the likelihood of open fractures, and the extremely low matrix hydraulic conductivity and porosity, there may be little or no water movement through the salt. However, to evaluate the travel time from the edge of the disturbed zone to the accessible environment, porous-media flow was conservatively assumed to prevail in the salt. Preliminary geologic studies have not identified anomalous features that would indicate the presence of preferential permeable flow paths in the salt stock. Fracture flow is considered unlikely and is not considered in the model. Flow is assumed to obey Darcy's law, and conservative ranges of the key hydraulic parameters are used; they are based on available generic in situ and laboratory data, including geophysical well logs. No site-specific data on hydraulic parameters are available. If alternative mechanisms of movement (e.g., diffusion) are considered, the estimated travel times to the accessible environment would be several million years.

The results of the stochastic modeling show a probability of less than .001 for travel times less than 1,000 or 10,000 years to the flank of the dome. Because of the very low hydraulic conductivities measured for essentially pure salt, the calculated times of lateral travel through 244 meters (800 feet) of salt are very long. Stochastic model calculations range over six orders of magnitude--the shortest being about 50,000 years and the median about 35 million years. Although the ranges of hydraulic parameters used in the analysis are considered reasonably conservative, a great deal of uncertainty is inherent in any prediction of travel times in millions of years. Of more significance than the absolute numbers, perhaps, is that the very long travel times suggested by the analysis indicate a likelihood that little or no ground water is present or moving through an appreciably thick, undisturbed mass of salt.

At Yucca Mountain, the stochastic analysis of the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment computes vertical ground-water movement downward through the unsaturated zone to the water table and then 5 kilometers laterally in the saturated tuff to the accessible environment. Travel time is calculated from a horizon 50 meters (164 feet) below the proposed repository downward through a minimum of about 135 meters (443 feet) of unsaturated welded and nonwelded tuff to the water table. Most of the total travel time is through the unsaturated zone, with about 140 years estimated for the travel time through the saturated zone to the accessible environment, once the water table is reached. Uncertainty in the variability and ranges in hydraulic conductivity and effective porosity are evaluated stochastically in the model, by randomly selecting ranges in hydraulic parameters in a series of 963 vertical columns. The calculated travel times range from about 9,500 to 80,250 years. This is based on an estimated maximum average net percolation of 0.5 millimeter per year. Ten realizations were run in each of the 963 columns of the model, with all but one of the 9,630 total realizations having a travel time of more than 10,000 years. The mean travel time in these calculations was about 43,300 years, and the median about 41,600, with a probability of about .0001 for a travel time of less than 10,000 years.

Changes in geohydrologic processes and conditions. This consideration covers the nature and rate of natural processes in the geologic setting that could ultimately change geohydrologic conditions so as to affect the ability of a repository to isolate the waste. It is directly related to the qualifying condition, which requires that geohydrologic conditions in the future be compatible with waste isolation. It is derived from the second favorable condition and the first potentially adverse condition. This consideration is second in importance because the preceding consideration, the ground-water travel time, reflects actual conditions, whereas this consideration reflects potential conditions.

Four contributing factors are identified for this consideration: climatic change, erosion, dissolution, and tectonics. On the basis of the discussion of these factors in Section 6.3.1 of each environmental assessment, it was concluded that climatic change is the only one of the four contributing factors that has a potential for significantly affecting the hydrologic system at any of the nominated sites during the next 100,000 years. Therefore, climatic change is the only potential cause of changes in the geohydrologic system that is addressed in the summary of site evaluations.

Judging from the record of the Quaternary Period in the area of the Davis Canyon site, climatic changes during pluvial conditions could increase precipitation, with a resulting increase in recharge to the ground-water system. Although it is uncertain to what extent higher rates of precipitation during the Quaternary Period have affected the hydrologic system, there is no evidence that ground-water parameters have changed significantly during the Quaternary Period. Also, the low permeability of the evaporite section separating the shallow hydrologic system from the deep confined system is expected to preclude any significant effects from expected climatic changes. Assuming that climatic changes during the next 100,000 years would be within the magnitude of past changes during the Quaternary Period, it does not appear that expected changes would adversely affect waste isolation at the Davis Canyon site during the next 100,000 years.

Judging from the record of the Quaternary Period, precipitation may be expected to increase over the current levels for the area of the Deaf Smith site, with consequent increases in recharge during the next 100,000 years. However, because of the low permeability of the evaporite section and the fine sedimentary interbeds that separate the shallow hydrologic system from the deep confined system beneath the proposed repository horizon, the variations in the nature and rates of surficial hydrologic processes that would result from future climatic changes would have little effect on the ability of a repository at the site to isolate waste during the next 100,000 years.

The climatic history of the Quaternary Period at the Hanford site indicates that any hydrologic impacts due to climatic changes would be localized or shallow phenomena (e.g., glacially induced flooding) that would not significantly change the waste-isolation potential of the deep basalt environment during the next 100,000 years. The factors responsible for this include the low permeability of the basalt flow interiors between the land surface and the proposed repository depth; the relatively low permeability of the deep basalt flows in comparison with shallow flows and interbeds; the existence of different flow systems with depth; the short duration of floods; and the likely persistence of the arid to semiarid climate that has existed at Hanford over the past 3 million years.

For the Richton site, the Quaternary history of the region indicates that climatic changes would have no significant influence on geohydrologic conditions at the site. Variations in geohydrologic processes that have occurred in response to Quaternary climatic cycles and the associated sea-level fluctuations result in slight increases and decreases in precipitation, hydraulic gradients, and rates of ground-water movement in the geohydrologic system surrounding the salt dome. Because of the very low hydraulic conductivity of the dome salt, such slight variations in hydrologic processes are expected to have minor, if any, effects on fluid movement within the dome. Therefore, no natural geohydrologic changes that would affect waste during the next 100,000 years are expected at the site.

At Yucca Mountain, the climatic record of the Quaternary Period suggests that pluvial conditions may recur sometime during the next 100,000 years, resulting in increased net infiltration (flux) and recharge, which could in turn raise the level of the water table toward the repository. Such changes would tend to reduce the time of ground-water travel between the disturbed zone and the accessible environment and could result in some increase in the quantity of ground water coming in to contact with the waste.

Ease of characterization and modeling. This consideration addresses the complexity of the geohydrologic system in terms of whether it can be characterized and modeled with reasonable certainty. It relates to the qualifying condition because characterization is the process of collecting and analyzing the data needed to develop and perform the modeling that is the means for predicting whether the site is compatible with waste containment and isolation. This major consideration is derived from the third favorable condition and the third potentially adverse condition. Since it is not an intrinsic physical characteristic of the geohydrologic setting, this consideration is not as important as the first two considerations; however, the ability to characterize and model the geohydrologic system with reasonable certainty is essential to evaluating the geohydrologic processes and properties that affect the ability of the site to contain and isolate waste.

Some of the contributing factors that influence the ease of characterization and modeling are the presence of faults, folds, brine pockets, dissolution effects, lithologic variations, interrelationships among hydrostratigraphic units, availability of testing techniques and analytic models, and understanding of flow mechanisms.

All five nominated sites are, to varying degrees, presently judged to have geologic and hydrologic complexities that could preclude their being readily characterized or modeled with reasonable certainty. Appreciable differences exist from one site to another in present levels of uncertainty, in part because of imbalances in the quality and quantity of available data and stages of scientific and technical investigation. A good understanding of the geohydrology of the site must be developed through the characterization process before it can be modeled with reasonable certainty. Modeling, in turn, can determine which physical characteristics need to be characterized. The difficulty of characterizing a site limits the ability to model it to an acceptable level of certainty. Although the third favorable condition is not present and the third potentially adverse condition is present at each site, it is expected that all five sites can be adequately characterized, though with varying levels of difficulty, in order to model their capabilities for long-term waste isolation to acceptable levels of certainty. A summary of the evaluation for this consideration for each site follows.

At the Davis Canyon site, the regional geologic framework and limited site-specific data suggest that the site is stratigraphically and structurally uncomplicated. Present stratigraphic information indicates that the proposed host salt bed contains minimal impurities and is a part of a reasonably well-understood sedimentary sequence. However, the present limited investigations leave many uncertainties. Structural features like faults, folds, and dissolution zones within the geologic setting could contribute to the difficulty of characterizing the system if they are found within the site. Ground-water movement through deep salt beds may be practically nil. There is a need to develop a clear understanding of the movement of fluids in salt and a site-specific ground-water hydraulics data base and to evaluate the potential for significant fracture flow in hydrogeologic units surrounding the host rock.

Because they are in similar geohydrologic settings, the Deaf Smith site and the Davis Canyon site are similar with respect to the ease of characterizing and modeling. Somewhat more data are presently available for the Deaf Smith site than for Davis Canyon, but fewer site-specific data are available for the salt sites than for the nonsalt sites. The greater number and frequency of nonsalt interbeds at Deaf Smith introduces complicating factors that are less likely to be present at Davis Canyon. As at Davis Canyon, the potential for significant fracture flow in geohydrologic units surrounding the host rock at Deaf Smith needs to be evaluated.

Generically, the horizontal distribution, variations in thickness and internal variations in the thickness of multiple basalt flows like those at Hanford may be more difficult to predict with confidence than for a sequence of sedimentary rocks like those formed at the bedded-salt sites, but site-specific investigations are more advanced at the Hanford site than at any of the salt sites. Consequently, the data base is appreciably larger and the complexities of site characterization and modeling are better defined at Hanford. Geologic features like faults, folds, internal variations in the thickness of flows, and variations in original intraflow structures known to exist in the regional setting could contribute to difficulty in modeling. Although uncertainties remain, preliminary studies have defined some basic geologic and hydrologic characteristics of the site. The existence of multiple basalt flows can complicate the characterization and modeling of the flow system, as well as provide multiple barriers to fluid movement. Accepted concepts and methods for studying saturated flow in a layered geohydrologic system are applicable to the basalt-flow system beneath Hanford. In some ways this may make characterization and modeling less complicated than at sites where applicable fluid-flow theory is either more complex or less advanced, such as for flow in salt or in the unsaturated zone at Yucca Mountain.

At the Richton site, the boundaries and dimensions of the salt stock are reasonably well defined. Limited available data on the interior characteristics of the salt stock suggest that it consists largely of pure salt that is free of significant anomalous features (e.g., large faults or clastic inclusions) that would provide important preferential ground-water flow paths. However, this concept of the dome's interior is uncertain and requires additional data for confirmation. Also, data on the surrounding geohydrologic environment mainly provide a regional picture of the ground-water flow system outside the dome, with little site-specific information to define flow relationships near the interface of the salt stock and the adjacent hydrostratigraphic units. These relationships may be complex and difficult to characterize, requiring an extensive data base that would be difficult to acquire. The characteristics of ground-water movement, if any, within salt are not well understood. Therefore, there is uncertainty in how to characterize and model fluid movement within the dome and any exchange of ground water between the dome and the surrounding geohydrologic units. On the other hand, because the accessible environment at the Richton Dome begins at the edge of the salt stock, the controlled area extends only to the periphery of the dome. The most critical part of the geohydrologic system to be characterized and modeled is confined to what may be an essentially homogeneous medium, the interior salt mass of the dome. In this respect, the flow system may be regarded as less complex and difficult to characterize and model than a system that contains a variety of lithologies or flow media between the repository and the accessible environment. However, the mechanism for ground-water flow in the salt, if such flow is significant, needs to be clearly defined during site characterization.

The geologic setting at Yucca Mountain may be considered somewhat complex, considering the structural history and volcanic origin of Yucca Mountain, and the inherent uncertainties in predicting the lateral and vertical variability of volcanic rock units. Also, the site is relatively complex from the standpoint of the availability of state-of-the-art models for measuring and analyzing flow in the unsaturated zone rather than the saturated zone. Known local faulting adds to the complexity of site characterization and modeling. However, the progress of site-specific geologic and hydrologic investigations is comparable to that at the Hanford site and more advanced than those performed at any of the salt sites. A preliminary site-specific geohydrologic data base has been established, and preliminary details of a conceptual flow model of the unsaturated zone, are defined. Advanced techniques are being developed to measure and analyze hydrologic parameters and to provide the information needed to refine models of flow in the unsaturated zone. Because of the need to develop advanced techniques and methods, the difficulty of characterizing and modeling the site with reasonable certainty may be greater than at sites in the saturated zone where currently accepted methods may be adequate for characterizing and modeling.

<u>Presence of suitable ground-water sources</u>. This consideration addresses the potential for radionuclides migrating from a repository to mix with ground-water sources suitable for crop irrigation or human consumption without treatment along flow paths to the accessible environment. It pertains to the qualifying condition with respect to limitations on radionuclide releases to the accessible environment and is derived from the second potentially adverse condition. This consideration is less important than the other three, because

it is unlikely that ground-water resources could be contaminated if a site is selected on the basis of its ability to isolate wastes, as reflected in the other three considerations. Of the five nominated sites, only Yucca Mountain has a finding of present for the second potentially adverse condition. A summary of the evaluation for each site follows.

At Davis Canyon a low-yielding aquifer containing good-quality ground water is present at a relatively shallow depth above the proposed repository horizon. However, ground water of good quality usable for irrigation or human consumption without treatment is not present along probable ground-water flow paths between the disturbed zone and the accessible environment. Although there is some potential for locally upward flow from the host rock, flow paths would be diverted laterally or downward at least hundreds of meters below the shallow aquifer because of the regionally downward vertical gradient below the shallow aquifer.

At the Deaf Smith site, ground-water flow is expected to be downward from the repository horizon. Water along this flow path has high total-dissolved-solids concentrations, making it unusable for crop irrigation or human consumption without treatment. There is good-quality ground water at shallow depths above the proposed repository horizon, but upward flow is not expected from the host rock.

At the Hanford site, shallow aquifers containing water of good quality exist above likely flow paths from the preferred repository horizon. However, ground water along likely flow paths between the disturbed zone and the accessible environment contains flouride, boron, and sodium concentrations considered too high for crop irrigation or human consumption without treatment.

At the Richton site, the accessible environment is considered to be at the flank of the salt stock. Therefore, ground water suitable for crop irrigation or human consumption without treatment does not occur along ground-water flow paths between the disturbed zone and the accessible environment.

At Yucca Mountain, flow paths from the disturbed zone in the unsaturated zone would be expected to be vertically downward to the water table and then laterally through the saturated zone to the accessible environment. Ground water along the flow paths in the saturated zone is of good quality and suitable for crop irrigation and human consumption without treatment.

Summary of the comparative evaluation

The Richton Dome is the most favorable of the five nominated sites for the geohydrology guideline on the basis of the four major considerations addressed under this guideline. Although site-specific data are sparse, resulting in appreciable uncertainty about flow in geohydrologic units surrounding the dome, and the mechanism of fluid flow in salt is uncertain, ground-water travel times at Richton are expected to be very long, and very little, if any, ground-water movement takes place within the salt stock. It is likely that no ground water or only very little is contained in the salt stock. Uncertainty with respect to the possible presence of anomalous features that could significantly affect flow through the dome would be addressed during site characterization. Hydrologic processes and conditions are not expected to change in a manner that would unfavorably affect the ability of the repository to isolate waste. Modeling of the geohydrologic system surrounding the dome is expected to be difficult. The limited data base results in appreciable uncertainty about relationships between the dome and the surrounding system. However, because all pathways to the accessible environment are expected to be entirely within the salt host rock, there is a high level of certainty that no usable ground-water sources would be encountered along pathways to the accessible environment.

Davis Canyon is the next most favorable site with respect to the geohydrology guideline if it is compared to Deaf Smith on the basis of equal distances to the accessible environment. It is slightly less favorable than the Richton Dome on the first and most important major consideration and is equally favorable with the other sites on the second major consideration. The pre-waste-emplacement travel time from the disturbed zone to the accessible environment appears to be less than that at the Richton Dome, and the travel time at Davis Canyon is longer than at the Deaf Smith site for equal distances to the accessible environment at both sites. The ground-water flux through the salt host rock, as indicated by the generic understanding of the hydraulic properties of salt, may be small if not nonexistent. There is no evidence for natural geohydrologic changes that will unfavorably affect the ability of the repository to isolate the waste during the next 100,000 years. On the basis of regional geologic studies, the structure and stratigraphy of the site are considered uncomplicated, but because of uncertainties with respect to the mechanism for ground-water flow in salt and the unlikely potential occurrence of a really extensive, fracture-controlled pathways in the brittle sedimentary interbeds, the level of difficulty in characterizing and modeling the geohydrologic system with reasonable certainty is expected to be comparable with that of the other sites. No aquifers containing ground water that is usable without treatment are present along any likely ground-water pathways between the edge of the disturbed zone and the accessible environment.

The Deaf Smith site is less favorable than the Richton and the Davis Canyon sites for the geohydrology guideline when the accessible environment is equally distant from the disturbed zone at Deaf Smith and at Davis Canyon. In such a case, it is less favorable on the first and most important major consideration, but equally favorable on the second major consideration. The estimated pre-waste-emplacement ground-water travel time between the disturbed zone and the accessible environment is shorter than that at Davis Canyon and Richton. However, if the distance to the accessible environment at Deaf Smith should be lengthened up to 5 kilometers and at Davis Canyon remain at 1 kilometer, Deaf Smith would be the more favorable site with respect to the pre-waste-emplacement ground-water travel time. Although the ground-water flux within the salt host rock is expected to be low, the presence of fine clastic interbeds in the host rock results in a potential for higher flux at Deaf Smith than at Davis Canyon or Richton. No natural changes in geohydrologic conditions that would unfavorably affect the ability of the site to isolate waste during the next 100,000 years are indicated. The structure and stratigraphy of the Deaf Smith site, on the basis of regional geologic studies, are considered uncomplicated. Because of uncertainties with respect to the mechanism for ground-water flow in salt and the unlikely potential for areally extensive, fracture-controlled pathways in the brittle interbeds, the level of difficulty in characterizing and modeling the geohydrologic system is expected to be comparable with that of the other sites. Finally, there is a high level of certainty that no aquifers containing ground water usable without treatment are present along ground-water pathways between the edge of the disturbed zone and the accessible environment.

The Hanford and the Yucca Mountain sites are both less favorable than the salt sites, but are in a comparable range of favorability with each other. Their comparative evaluations vary from one major consideration to another on the basis of available information. With respect to the pre-waste-emplacement ground-water travel time, Yucca Mountain is more favorable than the Hanford site. At Yucca Mountain, the ground-water flux through the host rock and the surrounding geohydrologic units, as indicated by the estimated maximum annual infiltration of 0.5 millimeter, is expected to be very low. A return to pluvial climatic conditions could increase the flux rate through the host rock and the surrounding geohydrologic units. This could also cause some rise in the water table toward the repository and some reduction in the time of travel to the accessible environment. Yucca Mountain and Hanford appear to have similar ranges of structural and stratigraphic complexity with unique geohydrologic complexities at each site. The complexity of fracture systems at Yucca Mountain may have important implications for characterizing and modeling flow in the unsaturated zone with reasonable certainty. Uncertainty in how to model flow in the unsaturated zone may also add to the difficulty of characterizing and modeling at Yucca Mountain. Ground-water sources of good quality are located along likely ground-water pathways from the proposed repository to the accessible environment at Yucca Mountain.

At the Hanford site, the ground-water flux through the saturated host rock and the surrounding geohydrologic units may be higher than in the unsaturated zone at Yucca Mountain. For the second major consideration, Hanford is more favorable than Yucca Mountain. Expected natural changes in hydrologic processes or geohydrologic conditions are not expected to affect the ability of a repository to isolate the waste during the next 100,000 years. Although commonly used modeling techniques may be applied, uncertainties in the structural and stratigraphic heterogeneity of the multiple basalt flows may contribute to modeling difficulties. At Hanford, no sources of ground water suitable for crop irrigation or human consumption without treatment are present along likely ground-water pathways from the edge of the disturbed zone to the accessible environment.

7.2.1.2 Geochemistry

The qualifying condition for postclosure geochemistry is as follows:

> The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in §960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-2), three major considerations are identified that influence the favorability of the site with respect to the qualifying condition are identified. In order of decreasing importance, they are (1) the expected rate of mass transfer of radionuclides from the waste package, (2) geochemical conditions that would inhibit the transport of radionuclides into the accessible environment, and (3) geochemical effects on the sorptive properties and strength of the host rock.

Evaluation of the sites in terms of the major considerations

Mass transfer of radionuclides. This consideration includes geochemical conditions in the immediate vicinity of the waste package after the permanent closure of the repository. It relates directly to the qualifying condition through the rates of radionuclide dissolution from the waste form and is based on the second and fourth favorable conditions and the first potentially adverse condition. The mass transfer of radionuclides is the most important consideration because it describes the processes by which radionuclides that are initially sealed in the solid waste form as part of the waste package will be released to the ground-water system (e.g., as ions, complexes, or particulates) or be contained within the engineered-barrier system. The most important contributing factors are the volumetric flow rate of the ground water that may contact the waste package and the chemistry of the ground water. Other contributing factors include the potential for the precipitation and sorption of radionuclides; the potential for the formation of colloids, complexes, and particulates; oxidation-reduction conditions; and the chemical reactivity of the ground water. A summary of the evaluation for each site follows.

The bedded salt of the Davis Canyon site contains little ground water. Sources of water in the repository horizon include brine inclusions and water of carnallite hydration, which constitute a small fraction of the host-rock volume. Thus, the volumetric flow rate of ground water due to the migration of these waters at the repository horizon is expected to be extremely low, if present at all. Because of their high magnesium content, the brines at Davis Canyon are potentially very corrosive for the stainless-steel container of the waste package. However, waste-package degradation should be limited because the amount of water in contact with the waste is expected to be small. The formation of some colloids will be inhibited by the high salinity of brine. Because of their high concentration in the brines, chlorides, sulfates, and carbonates could form complexes with radionuclides, which may increase the mobility of some radionuclides. Although chemically reducing conditions are expected in the host rock and the underlying aquifers, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The host rock at the Deaf Smith site is bedded salt that may contain more water than the rock of the other two salt sites. The salt of the lower San Andres Unit 4 contains intercrystalline muds and interbeds of mudstone containing clay; these muds and interbeds could contribute water in addition to that provided by brine inclusions. Thus, the total amount of ground water that is expected to enter the repository through brine migration should be extremely small. These brines have a high magnesium content and are

Table 7-2. Guideline-condition findings by major consideration--geochemistry[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: EXPECTED RATE OF MASS TRANSFER FROM THE WASTE-PACKAGE SUBSYSTEM					
Favorable condition 2					
Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	P	P	P	P	P
Favorable condition 4					
A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.	P	P	P	P	P
Potentially adverse conditions 1					
Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: GEOCHEMICAL CONDITIONS THAT WOULD INHIBIT RADIONUCLIDE TRANSPORT IN THE FAR FIELD					
Favorable condition 1					
The nature of rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.	P	P	P	P	P
Favorable condition 2					
Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.	P	P	P	P	P

Table 7-2. Guideline-condition findings by major consideration--geochemistry[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: GEOCHEMICAL CONDITIONS THAT WOULD INHIBIT RADIONUCLIDE TRANSPORT IN THE FAR FIELD (Continued)					
Favorable condition 5					
Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.	NP	NP	P	NP	P
Potentially adverse condition 3					
Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.	NP	NP	NP	NP	P
MAJOR CONSIDERATION 3: GEOCHEMICAL EFFECTS ON THE SORPTIVE PROPERTIES AND ROCK STRENGTH OF HOST ROCK					
Favorable condition 3					
Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.	P	P	P	P	P
Potentially adverse condition 2					
Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

potentially very corrosive to the stainless-steel container of the waste packages, but the small amount of water expected in the repository will limit waste-package degradation. The formation of some, but not all, colloids will be inhibited by the high salinity of brine. Because of their high concentrations in the brine, chlorides, sulfates, and carbonates could form complexes with radionuclides, which may increase the mobility of some radionuclides. While chemically reducing conditions are expected in the host rock and underlying aquifers, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The Hanford site may have a somewhat higher flow rate of water past the waste package than other sites. The bentonite and crushed-basalt packing material that will surround the low-carbon-steel disposal containers is expected to significantly reduce the flow rate of ground water that could come in contact with the waste. The ground water at Hanford has a low salinity in comparison with the salt sites and a high pH, which tends to reduce the rates of container corrosion. In addition, the chemically reducing conditions that are expected would lower the solubility of redox-sensitive radionuclides and further lower the rates of container corrosion. However, alpha and gamma radiolysis may result in localized oxidizing conditions around the disposal container. Ground water at the repository level contains carbonate and hydroxyl ions, which could complex with escaping radionuclides, thereby increasing their mobility. Interactions between the waste package and ground water may result in the precipitation of iron-silica that would tend to scavenge radionuclides. In addition, sorption is expected to play a major role in the retardation of radionuclide transport.

Richton Dome is probably driest of the salt sites because of the small quantity of brine inclusions typical of domed salt. The volumetric flow rate of ground water at the repository horizon from brine migration is expected to be extremely low. As a result, waste-package degradation should be limited in spite of the inherently corrosive nature of brine. The formation of some, but not all, colloids should be inhibited by the high salinity of brine. The chloride and sulfate present in the brine could form complex with, and thus increase the mobility of, some radionuclides. While chemically reducing conditions are expected in the host rock, the ability of the water-rock system to maintain reducing conditions in the presence of alpha and gamma radiolysis may be limited.

The Yucca Mountain site is in a geologic environment with a very low ground-water flux through the candidate repository horizon. The low salinity and the nearly-neutral pH of the ground water would tend to reduce the corrosion rate of the disposal container; however, the ground water is oxidizing and would tend to make the waste-package environment somewhat more corrosive than water with lower oxidation-reduction (redox) conditions. The potential for the formation of inorganic complexes in the ground water of the Yucca Mountain site is probably low because of the very low salinity of the water, although the carbonate present in the ground water may increase the mobility of some radionuclides. The nearly-neutral pH of the water is conducive to the low solubility of oxides and hydroxides of some radionuclides, especially the actinides. In addition, interactions between the waste package and ground water may result in the precipitation of iron-silica, which would tend to scavenge radionuclides.

Radionuclide transport. This major consideration relates directly to the qualifying condition with respect to the natural barriers that would inhibit the transport of radionuclides into the accessible environment; it is based on the first, second, and fifth favorable conditions and the third potentially adverse condition. The contributing factors that are the most important for the quantitative evaluation of radionuclide transport and retardation include sorption and precipitation as well as redox conditions. A summary of the evaluation for each site follows.

At the Davis Canyon site, the geochemical processes within the host rock are not expected to be altered by anything other than the dissolution of the host salt, and available data suggest that dissolution will not be a problem at Davis Canyon. The salt contains very small amounts of clay minerals that could enhance the sorption of migrating radionuclides. Conversely, the high ionic strength of the brine would tend to decrease the sorptive capacity of these clays. Redox conditions in the interbeds within the salt cycles and in the aquifer beneath the salt of the Paradox Formation are reducing, which decreases the solubility of some key redox-sensitive radionuclides. However, the chloride and carbonate, which are present in the brines in high concentration, could form complexes with radionuclides, and this may increase the mobility of these radionuclides. However, sulfate solubility relationships may limit the concentrations of some radionuclides.

At the Deaf Smith site, geochemical processes would not be expected to be altered by anything other than the dissolution of the host salt, and dissolution is not expected to be a problem at the site. The salt of the Deaf Smith site contains numerous mudstone inclusions and interbeds, and approximately half of them are composed of clay and clay-sized particles. Although it is possible that the clay could increase the sorption of migrating radionuclides, the high ionic strength of the brine tends to decrease the sorptive capacity of the clay. Ground water in the aquifer that underlies the salt cycles of the Palo Duro Basin is reducing, which further decreases the solubility of some key redox-sensitive radionuclides. However, the chloride and carbonate present in the brine could form complexes with radionuclides, thereby increasing their mobility. However, sulfate solubility relationships may limit the concentrations of some radionuclides.

At the Hanford site, little change is expected in the geochemical processes within the basalts because of the depth and the saturation of the repository horizon. The dense interior of the host rock should afford some degree of physical retardation for radionuclides. The geochemical environment of the site is favorable for the precipitation and sorption of radionuclides (i.e., reducing ground water and abundant secondary clays and zeolites from lining fracture and fragment surfaces). The secondary mineral assemblages that would be formed are believed to be stable under the temperatures expected in the disturbed zone. Since the data on colloids, particulates, and organics are limited, these factors cannot be fully evaluated at present. The ground water is of low salinity, but it contains carbonate and hydroxyl ions that could form complexes with radionuclides.

At the Richton site, the geochemical processes within the host rock would not be expected to be altered by anything other than dissolution. Available data suggest that dissolution should not be a problem at the site. The salt of the Richton Dome is predominantly halite with a very low water content.

Available data suggest that the water contained in fluid inclusions in the salt is reducing and should decrease the solubility of some redox-sensitive radionuclides. Because of their high concentrations, the chloride, sulfate, and carbonate present in the brines could form complexes with radionuclides, thereby increasing their mobility. However, sulfate solubility relationships may limit the concentration of some radionuclides.

At Yucca Mountain, little water is expected to pass through the tuff. The predominant mode of water migration is currently thought to be matrix flow along much of the ground-water-flow path. Sorption and diffusion are expected to delay or retard the migration of radionuclides. The oxidizing nature of the water may inhibit radionuclide precipitation and sorption for redox-sensitive radionuclides. The abundance of highly sorptive secondary clays and zeolites along ground-water-flow paths should provide a sorptive barrier to most radionuclides. Redox-sensitive radionuclides like technetium may not be retarded by sorption. The low salinity of the ground water would be conducive to the formation of some colloids since certain actinides form colloids in dilute nearly-neutral waters. Since the data on colloids, particulates, and organics are limited, these factors, cannot be fully evaluated at present.

Sorption and rock strength. This consideration addresses geochemical processes that could adversely affect the sorptive capacity or strength of the host rock, or both. The consideration relates directly to the qualifying condition with respect to the retardation of radionuclides by natural barriers in the repository and along ground-water-flow paths to the accessible environment; it is derived from the third favorable condition and the second potentially adverse condition. Sorption and rock strength are considered less important that the preceding considerations because they would affect only a small percentage of the total rock mass surrounding the repository. Change in the sorptive capacity of the host rock minerals is the most important contributing factor under this consideration because of the potential effect on the retardation of radionuclides. The major contributing factors for this consideration are the stability of mineral assemblages, the effects of mineral alteration on sorption, and the effects of mineral alteration on rock strength. A summary of the evaluation for each site follows.

The mineral assemblage at the Davis Canyon site may contain carnallite, which could dehydrate when subjected to repository heat and release magnesium-rich brines. High-magnesium brines would accelerate the degradation of the waste packages and subsequently lead to a release of radionuclides. In addition, alteration of the carnallite could reduce the strength of the host rock. However, the quantity of carnallite at the Davis Canyon site is expected to be small, and carnallite should have little effect on radionuclide containment.

The mineral assemblage at the Deaf Smith site includes interbeds and inclusions of mudstone. It is assumed that these consist of approximately 50 percent clay minerals that may dehydrate under the geochemical conditions within the repository. However, because of the small volume of clay minerals, the alteration of these materials is not expected to affect the retardation of radionuclides or the strength of the host rock.

The host rock at the Hanford site consists of basalt and a number of sorptive secondary minerals (e.g., clays, zeolites). Laboratory tests suggest that repository conditions may result in the formation of a mineral assemblage similar to the secondary minerals formed naturally in basalt as a result of hydrothermal alteration. Although the hydrothermal conditions near the repository could adversely affect the sorptive capacity of some of these minerals, there is abundant evidence that hydrothermal conditions could alter the volcanic materials to more sorptive materials (e.g., clays and zeolites). In general, the effects of the repository on rock strength are expected to be negligible.

At the Richton site, the mineral assemblage consists mainly of halite with some anhydrite. Because of the stability of the minerals at this site, it is expected that no geochemical alteration or reduction in rock strength would affect the transport of radionuclides.

The mineral assemblage in the host rock of the Yucca Mountain site consists of 98 percent quartz, feldspar, and cristobalite, with small amounts of secondary clays and zeolites. The sorptive capacity of the host rock is likely to be slightly reduced by the dehydration of clays and zeolites in the disturbed zone and remain unaffected in the surrounding rocks. Only very small amounts of volcanic glass are likely to be present. Rock strength is not expected to be affected by the geochemical conditions in the repository.

Summary of comparative evaluations

Hanford and Yucca Mountain are the most favorable sites for the geochemistry guideline. These two sites are expected to have the most favorable geochemical conditions with respect to the waste package and radionuclide retardation. The basalt at Hanford should respond favorably to geochemical conditions in the repository by creating additional sorptive capacity. Hanford also has more favorable redox conditions. Yucca Mountain has unsaturated conditions as well as the additional radionuclide-retardation effects of matrix diffusion.

The Davis Canyon, the Deaf Smith, and the Richton sites are favorable for all major considerations and are essentially equivalent with respect to the geochemistry guideline. They are less favorable than the nonsalt sites because the sorptive capacity of salt is very limited and the brines at these three sites could reduce the lifetime of the waste package. Moreover, the geochemical conditions in the salt sites are not expected to enhance the retardation of radionuclides through the alteration of the host rock to the degree that is expected at Hanford. The amount of brine, however, will probably be small, and the transport of radionuclides by this brine is likely to be quite limited. Therefore retardation due to geochemical effects may be of limited importance.

7.2.1.3 Rock characteristics (postclosure)

The qualifying condition for postclosure rock characteristics is as follows:

> The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in §960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-3), three major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. In order of decreasing importance, they are (1) the potential effects of repository-induced heat on waste containment or isolation, (2) the complexity of engineering measures required to ensure waste containment and isolation, and (3) flexibility for locating the underground facility to ensure waste isolation. These major considerations are, in turn, influenced by a number of more-specific rock properties and in situ conditions.

Evaluation of the sites in terms of the major considerations

Effects of repository-induced heat. This consideration is derived from the second favorable condition and second and third potentially adverse conditions. The factors contributing to this condition are the thermal properties of the host rock, such as thermal conductivity and the coefficient of thermal expansion; mechanical properties, such as a sufficiently high ductility for fractures to heal; thermomechanical behavior, such as the potential for thermally induced fractures; and geochemical conditions, such as the potential for brine migration and the hydration or dehydration of mineral components. This consideration also takes into account the effect of repository-induced heat on the integrity of the host rock and the surrounding rock units. Because of the potential effects of these factors on waste isolation, this major consideration is more important than the other two. A summary of the evaluation for each site follows.

At Davis Canyon, the effect of repository-induced temperature increases after closure can be favorable because of increases in the rate of salt creep, which would seal the underground openings and reconsolidate and recrystallize the salt backfill. Adverse impacts from a temperature increase would include the migration of brine within the host rock to the heat source and an increase in gas pressure if brines or gases are present in significant quantities. Limited site-specific data indicate very little brine is present at Davis Canyon. The adverse geochemical impacts from a temperature increase could also include mineral alteration and the dehydration of carnallite, but test

Table 7-3. Guideline-condition findings by major consideration—rock characteristics (postclosure)[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL IMPACT OF REPOSITORY-INDUCED HEAT ON WASTE CONTAINMENT OR ISOLATION					
Favorable condition 2					
A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.	P	P	P	P	P
Potentially adverse condition 2					
Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.	P	P	NP	P	NP
Potentially adverse condition 3					
A combination of geologic structure, structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: COMPLEXITY OF ENGINEERING MEASURES REQUIRED TO ENSURE WASTE CONTAINMENT AND ISOLATION					
Potentially adverse condition 1					
Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: SIGNIFICANT FLEXIBILITY IN HOST-ROCK DIMENSIONS TO ENSURE ISOLATION					
Favorable condition 1					
A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.	P	NP	NP	P	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

results to date indicate that impacts from alteration or dehydration are not significant if the carnallite is under confining pressure.

At the Deaf Smith site, repository-induced temperature increases in the salt would contribute to creep effects like those at Davis Canyon. The rate of salt creep is expected to be higher at the Deaf Smith site than at Davis Canyon. The potential for creep-related disturbances to the interbeds and aquifers above the repository adds complexity at the Deaf Smith site.

At the Hanford site, repository-induced temperature increases may alter the permeability of the rock mass, through changes in fractures. It will also increase the in situ stresses in the vicinity of the excavations, possibly resulting in a readjustment of the rock mass and alterations in the local hydrologic regime. The rates of hydrochemical reactions among the various components will increase with the addition of heat. This is expected to have a positive effect on the isolation capabilities of the Hanford site.

At the Richton site, the effect of the repository-induced temperature increase on salt creep is expected to enhance the isolation capability of the site. The rate of salt creep at the Richton Dome is expected to be similar to that at the Deaf Smith site. The absence of stratification and the higher purity of the salt at Richton Dome should result in a less-anisotropic mechanical response to the temperature increase. The Richton Dome has a low brine content, and therefore minimal effects from brine migration are expected. Thermally induced uplift could affect the caprock (gypsum) over the dome, but modeling results indicate that such uplift is not expected to adversely affect the isolation capability of this site.

At Yucca Mountain, the problems associated with repository-induced heat are negligible, primarily because the underground facilities are in the unsaturated zone. The thermal pulse will modify the permeability of existing fractures since thermal expansion decreases the permeability of the rock mass, which in turn reduces the potential for new fractures. The Yucca Mountain site has some rock-mass heterogeneities that could cause an undetermined, but probably not adverse, response to heat (from both the variability of the content of lithophysae and the regions in which the tuff has been welded to different degrees). Although only preliminary measurements from surrounding strata are available, the rock stresses are not expected to be increased to unacceptable levels by the thermal response.

Complexity of engineering measures. This consideration includes in situ characteristics and conditions that could require engineering measures beyond reasonably available technology to ensure waste containment and isolation. Engineering measures relate directly to the qualifying condition through the specification that reasonably available technology is to be used to meet the requirements of the engineered-barrier system. It is derived from the first potentially adverse condition. The major contributing factors to this consideration are the uncertainty about the durability of man-made sealing material after closure and the effects of the in situ environment on engineered-barrier performance (e.g., the effects of brine on the disposal container). Complexity of engineering methods is considered less important than repository-induced heat effects because of the greater potential of heat effects to impair the isolation capabilities of the site. A summary of the evaluation for each site follows.

The sealing of boreholes and shafts at Davis Canyon is not expected to require complex engineering methods. The processes of sealing a repository in salt can be accomplished with technology developed in the salt-mining industry. With regard to interactions between the waste and the host rock, brines at Davis Canyon, if present, could accelerate the corrosion of the waste package.

Like Davis Canyon, the Deaf Smith site is not expected to require complex engineering methods. The site is expected to require particularly careful sealing to isolate the shaft from the Ogallala aquifer. The repository can be sealed by technology devéloped in the salt-mining industry from experience in drilling in the Palo Duro Basin. Interactions between the brine that may be present and the waste packages could accelerate the corrosion of the waste package, which could diminish the containment capabilities of the engineered-barrier system.

The ability to properly seal shafts and boreholes in basalt and to confirm the long-term effectiveness of seals are major concerns at Hanford. In particular, the sealing of the overlying aquifers from the repository horizon will require additional engineering measures to effectively isolate the waste. With regard to interactions of the various components of the engineered-barrier system, the expected presence of a geochemically reducing environment after closure and the sorptive properties of the secondary minerals formed in fractures in basalt are likely to enhance the containment and isolation capability at Hanford.

At the Richton site, shafts through the overlying saturated sediments and the caprock can be sealed by using technology similar to that used in mines in other salt domes. The sealing of the repository is not expected to require complex engineering measures. Interactions between the brine that may be present in the Richton Dome and the waste package could accelerate the corrosion of the waste package, which could diminish the containment capabilities of the engineered-barrier system.

At Yucca Mountain, the host rock is unsaturated; furthermore, construction experience at the Nevada Test Site shows that technology for borehole and shaft seals is readily available. In addition, since the seals will be required to perform only as well as the overall rock-mass permeability, long-term seal performance requirements are not particularly demanding. With regard to the interactions of the various components of the engineered-barrier system, the expected rock and geochemical conditions are favorable.

Flexibility. This consideration pertains to flexibility in determining the depth, configuration, and location of the underground repository. It relates to the qualifying condition because flexibility in locating the repository at a site increases the favorability of the site with respect to the qualifying condition. Added flexibility in locating the repository will help avoid geologic features or anomalies that could adversely affect the isolation capabilities of the site. Even after requirements for preclosure flexibility have been satisfied, added flexibility may still be necessary to satisfy this postclosure consideration in terms of the depth of excavations, the orientations of drifts and their intersections, and the location of seals. A greater volume of host rock could provide isolation capability over and above the degree deemed minimally acceptable. On this basis, the contribution of flexibility to waste isolation is less than that of the other two considerations for this guideline. A summary of the evaluation for each site follows.

The host rock at Davis Canyon is expected to offer significant flexibility in that the available thickness appears to be several times greater than the required thickness. In addition, the potential host rock extends laterally underground for many kilometers. The presence of significant interbeds, impurities, gases, and structural features and their potential for adverse effects on flexibility are not yet well defined at this site.

At the Deaf Smith site, numerous interbeds may limit the vertical flexibility of locating a repository with respect to isolation considerations. In contrast, the host rock is expected to extend laterally for a considerable distance. The presence of impurities, brines, gases, and structural features and their potential to adversely affect flexibility are not yet well defined.

The Hanford site appears to offer restricted vertical but extensive horizontal flexibility with respect to isolation considerations. The thickness of the basalt can vary significantly over short distances, and the predictability of host-rock thickness is considered to be uncertain because of a limited data base.

The Richton site provides significant vertical flexibility and adequate lateral flexibility. Unfavorable internal structures within the salt dome could be encountered during site characterization; if present, they would diminish the flexibility for locating underground facilities at this site.

The host rock at Yucca Mountain offers significant vertical flexibility, but lateral flexibility is restricted by minor faults, shallow overburden, or site anomalies. The lateral homogeneity of the potential host rock outside the primary repository area has not been established.

Summary of comparative evaluation

Yucca Mountain is the most favorable site on the basis of the two most important considerations. It is expected that the response of the host rock to the heat loading of the repository would have an overall favorable effect. Furthermore, the long-term seal-performance requirements at Yucca Mountain are not expected to be very demanding. Although the flexibility for locating the underground facility is limited at Yucca Mountain, this does not outweigh the favorability of the other more important considerations.

The Davis Canyon and the Richton sites are next in favorability for the rock-characteristics guideline. At Davis Canyon, the repository-induced temperature increase is expected to improve the performance of the site by increasing the rate of salt creep, which would seal the underground openings by reconsolidating the salt backfill. However, the impact of the brine migration toward the heat source needs to be assessed. The sealing of boreholes and shafts at Davis Canyon is not expected to require complex engineering methods. Davis Canyon is also expected to offer significant flexibility in locating the repository because of its lower brine content. The Richton site is more favorable than Davis Canyon for the repository-induced heat consideration. Richton is less favorable than Davis Canyon and Yucca Mountain on the basis of the major consideration for the complexity of engineering methods because of potential problems with sealing the repository from the overlying sediments and caprock. The Davis Canyon and the Richton sites are equally favorable with respect to host-rock flexibility. On the basis of these comparisons, Davis Canyon and Richton are approximately equal in favorability under this guideline.

Hanford is somewhat less favorable than the Yucca Mountain, the Davis Canyon, and the Richton sites for this guideline. Although Hanford is very favorable with respect to the effects of repository-induced heat, it may require complex engineering methods because of potential difficulties in sealing the overlying aquifers from the repository horizon. There has been little experience in sealing hard-rock mines to the degree that will be required for the repository. Hanford also appears to offer restricted vertical flexibility with respect to isolation considerations.

The Deaf Smith site is considered to be somewhat less favorable with regard to the rock-characteristics guideline. It is the least favorable site for the major consideration of repository-induced heat because of more-extensive interbeds. It is also the least favorable site under the third major consideration because the presence of interbeds limits its vertical flexibility. However, these considerations are not likely to significantly affect the ability of the site to contain or isolate waste.

7.2.1.4 Climatic changes

The qualifying condition for the climatic changes guideline is as follows:

> The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-4), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: the effect of future climatic changes on the ability of the site to isolate waste. Contributing factors include Quaternary climatic cycles and the in situ conditions at a site. The major consideration is directly related to the qualifying condition through the consideration of

Table 7-4. Guideline-condition findings by major consideration--climatic change[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.	P	P	P	P	P
Favorable condition 2					
A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	NP	NP	NP	NP	NP
Potentially adverse condition 1					
Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.	NA	NA	NA	NA	NP
Potentially adverse condition 2					
Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All the conditions in this table are associated with one major consideration: the effect of climatic changes on the ability of the site to isolate the waste.

climatic changes that may affect waste isolation. It is derived from the two favorable conditions and the two potentially adverse conditions. A summary of the evaluation for each site follows.

Evaluation of sites with respect to the major consideration

At the Davis Canyon site, climatic changes during the Quaternary Period are thought to have increased precipitation by as much as 120 percent. Increased precipitation during the Pleistocene may have increased recharge rates and flow through hydrostratigraphic units as well as rates of erosion and dissolution. Estimates of increased precipitation are based on regional data that cover the last 13,000 years and site-specific geomorphic data. Although it is uncertain by how much increased precipitation affected the hydrologic system, it does not appear that changes of the same magnitude would adversely affect waste isolation. To establish bounding cases for the potential effects of increased precipitation on the hydrologic system, a simple worst-case assumption was made in which increased precipitation raises the water table to the ground surface in the Abajo Mountains. The resulting hydraulic gradient between the Abajo Mountains and the Colorado River is not significantly greater than the present maximum apparent hydraulic gradient estimated from hydrologic tests. Preliminary estimates of the rates of erosion and dissolution during the Quaternary Period, if projected into the future, would not affect the isolation capability of the host rock, because no significant changes in flow parameters, such as porosity or permeability, have been identified in the Quaternary Period. Preliminary estimates of the maximum rates of incision over the next 100,000 years are approximately 40 meters (132 feet). Although increased rates of incision may alter the surface-water system, increased incision at the surface is not expected to affect the integrity of a repository at a depth of 885 meters (2,900 feet).

At the Deaf Smith site, regional data indicate that lower temperatures and increased effective moisture occurred during the Pleistocene. The Quaternary record suggests cyclical increases in precipitation during pluvial cycles. Increases in precipitation during future pluvial conditions would increase surface-water ponding and growth of vegetation. The increased vegetation would tend to decrease the rates of erosion, though localized increases in erosion could occur near escarpments. Although these climatic changes would change the surface-water system, they are not expected to reduce the waste-isolation capabilities of the host rock. Potential effects of Quaternary climatic cycles on the hydrologic system include changes in the rates of recharge and increased rates of dissolution at salt margins. Increased recharge to the upper hydrostratigraphic unit would result in an increase in the hydrologic gradient between this unit and the underlying units, but models of this process show no significant effect in the underlying units for more than 10,000 years. Although the data are insufficient to quantify the effects of these changes on the hydrologic system, there is no evidence to suggest that Quaternary climatic changes had a significant effect on the ground-water system.

At the Hanford site, if glacially induced catastrophic floods recurred, they would alter the present surface-water system by increasing runoff, the rates of erosion, and ponding. The net effect of catastrophic flooding would be sediment aggradation. These changes in the surface-water system would be short-lived and are not expected to significantly affect the confined aquifers of the Grande Ronde basalts. If glaciation were to recur, the major adverse effects would be increased recharge from meltwater and catastrophic flooding. Increased recharge may be expected to cause some rise in the potentiometric surfaces of shallow aquifer systems, but the transient nature of increased recharge is such that significant long-term effects on the confined aquifers of the Grande Ronde basalts are not expected.

For the Richton site, the data are insufficient to quantify the effects of future climatic changes on the surface-water system. However, regional data suggest that, if the climate returned to a glacial maximum, increased precipitation would slightly increase erosion and ground-water recharge. During the late Wisconsinian glaciation, the sea level in the Gulf of Mexico was 100 to 130 meters (330 to 430 feet) below the present mean sea level. This regional change in base level, combined with regional uplift, resulted in stream entrenchment. Geomorphic evidence in the region suggests that stream entrenchment in major rivers was on the order of 30 meters (100 feet). This would have little effect on the deep confined ground-water system around the Richton Dome. A future interglacial cycle accompanied by a melting of the ice sheets equivalent to Pleistocene interglacials could cause a rise in sea level of 5 to 10 meters (16 to 32 feet). An equivalent rise in sea level would not inundate the surface of the site, which is at least 50 meters (164 feet) above the mean sea level. Thus, the analysis of regional data suggests that future climatic changes would not affect the surface-water or the ground-water systems to the extent that the isolation capabilities of the site would be affected.

Analysis of data on the effects of climate changes in the vicinity of Yucca Mountain suggests that surface-water systems changed little during the Quaternary Period and are not expected to change significantly in the next 10,000 years. The present surface-water system was established by early Quaternary time. It is unlikely that the maximum probable climatic change, from arid to semiarid conditions, would cause a significant change in the present drainage system. Climatic data suggest that Quaternary climatic changes had the following effects on the ground-water system: increased recharge; increased elevation of, and gradients in, the water table; and upgrade shifts in discharge points. Data from the region suggest that the effects of these changes were minor. One exception may be the effect of increased recharge on the hydrologic system, though the magnitude of the increased recharge has not yet been quantified.

If pluvial conditions were to occur, increased recharge may have a significant effect on the ground-water flux and may raise the level of the water table. Preliminary modeling of increases in the water table during a full pluvial cycle, assuming a 100-percent increase in precipitation, suggests a maximum rise of 130 meters (427 feet). Such a rise in the water table would not saturate the repository. Furthermore, considering the various sources of uncertainty in the model--such as the method used to simulate recharge, the assumption that the response of the water table is instantaneous, and the use of a two-dimensional model to simulate three-dimensional flow--the prediction of a 130-meter rise in the water table is uncertain and may not be realistic. It is unlikely that increased recharge from a return to pluvial conditions would significantly increase radionuclide transport to the assessible environment.

Summary of the comparative evaluation

The available data suggest that the Davis Canyon, Deaf Smith, Hanford, and Richton sites are equally favorable with respect to the major consideration and the guideline on climatic changes. At these sites changes in the surface-water system over the next 100,000 years are not expected to adversely affect isolation capabilities. Climatic changes during the Quaternary Period may have had minor effects on the ground-water systems. In the next 10,000 years, none of these sites is expected to undergo climatic changes that would decrease the ability of the natural barriers to isolate the waste.

The Yucca Mountain site is less favorable than the other sites because future climatic changes may produce a significant increase in recharge to the geohydrologic system. Assuming an eventual return to pluvial conditions, preliminary modeling suggests that increased recharge may increase the ground-water flux, decrease the ground-water travel time, and increase the elevation of the water table. The potentially increased flux, combined with a substantial rise in the water table, introduces greater uncertainty in assessing the potential effects of future climatic changes on the Yucca Mountain site. However, climatic conditions during the next 10,000 years would not be likely to significantly increase radionuclide releases to the accessible environment.

7.2.1.5 Erosion

The qualifying condition for erosion is as follows:

> The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of potentially disruptive erosional processes the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-5), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: the effects of erosional processes on waste isolation. The major consideration is derived from the three favorable conditions and the two potentially adverse conditions and evaluates effects of erosional processes on waste isolation. It is directly related to the qualifying condition through emphasis on the ability to isolate waste.

Table 7-5. Guideline-condition findings by major consideration—erosion[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
Site conditions that permit the emplacement of waste at a depth of least 300 meters (984 feet)below the directly overly ground surface.	P	P	P	P	NP
Favorable condition 2					
A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than 1 chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.	P	P	P	P	P
Favorable condition 3					
Site conditions such that waste exhumation would not be expected to occur during the first 1 million years after repository closure.	P	P	P	P	P
Potentially adverse condition 1					
A geologic setting that shows evidence of extreme erosion during the Quaternary Period.	NP	NP	NP	NP	NP
Potentially adverse condition 2					
A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are associated with one major consideration: effects of erosional processes on waste isolation.

Contributing factors include the depth of waste emplacement, evidence of extreme erosion during the Quaternary Period, the potential for uncovering the waste, and the assessment of future erosion rates and geomorphic processes on the basis of the climatic, tectonic, and geomorphic evidence of erosion rates and patterns during the Quaternary Period. These factors cannot be evaluated individually to make a judgment on the qualifying condition; they must be evaluated together. It is for this reason that only one major consideration is identified. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major consideration

At Davis Canyon, the host-rock unit (salt cycle 6) is estimated to occur at a depth of approximately 885 meters (2,900 feet). During the Quaternary Period, erosion in the candidate area has been almost continuous, though long-term rates of incision are not thought to be extreme. Stream erosion is predicted to erode no more than approximately 3 meters (12 feet) below the present ground surface in 10,000 years. Streams in the region have been predicted to erode up to 240 meters (800 feet) into their present channels (using long-term incision rates) during the first million years after repository closure. The Quaternary geologic record indicates that geomorphic processes should not adversely affect the ability of the repository to isolate the waste. This includes a preliminary assessment of the eastward propagation of the graben systems west of the site. Considering the planned depth of the repository, present knowledge suggests that it is highly unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

At the Deaf Smith site, the host rock is in Unit 4 of the Lower San Andres Formation, where the top of the unit is 700 to 760 meters (2,300 to 2,500 feet) below the surface. No evidence is recorded of extreme erosion at the site. Extrapolation from a relatively high river-incision rate in Holocene time shows erosion to a depth of 63 meters (210 feet) in the next 10,000 years. Projections of average Quaternary conditions indicate that erosion of 100 meters (330 feet) would occur over the next 1 million years. Projections of Quaternary erosional conditions indicate that the waste would remain isolated after 10,000 years. Considering the planned depth of the repository, it is unlikely that erosion will lead to releases of radionuclides to the accessible environment in the next 10,000 years.

At the Hanford site, the depth to the Cohassett flow top is 869 to 943 meters (2,850 to 3,093 feet). The site does not show evidence of extreme erosion during the Quaternary Period. Because the depth of erosion is geomorphically controlled by base level, future incision is limited to depths above the minimum sea level. Past glacially induced sea-level changes indicate that erosion at the site could proceed no further than about 440 meters (1,443 feet) above the top of the candidate horizon. The depth of the candidate horizon and the geologic setting of the site are such that the waste would not be expected to be uncovered during the first million years after repository closure. There is little chance, if any, of erosion leading to a release of radionuclides to the accessible environment over the next 10,000 years.

At the Richton site, the waste would be emplaced at a depth of 646 meters (2,119 feet). No evidence of sustained extreme erosion during the Quaternary Period is found in the geologic setting of the site. The geomorphic processes that have been in operation during the Quaternary Period have resulted in a long-term erosion rate of 1.2 meters (4 feet) per 10,000 years. This rate would result in the removal of 120 meters (394 feet) of material in 1 million years, leaving 526 meters (1.718 feet) of material over the repository. The chance of erosion removing the entire thickness of overdome sediments is much less than 1 in 1 million. Thus, it is very unlikely that erosion over the next 10,000 years would lead to any radionuclide releases to the accessible environment.

At Yucca Mountain, the minimum thickness of the overburden above the repository would be about 230 meters (750 feet). For about 50 percent of Yucca Mountain, the overburden is more than 300 meters (984 feet). Average stream-incision rates during the past 300,000 years have not been extreme, and there has been little change in the patterns of erosion at the site during the Quaternary Period. On the basis of average stream-incision rates, the shallowest portion of the repository is expected to remain buried much longer than 1 million years. Over a period of 10,000 years, erosional processes would be expected to remove only 1 meter (3 feet) of overburden. The probability that erosion would induce a loss of isolation is less than 1 in 1 million over the next 10,000 years. Thus, although the Yucca Mountain site does not meet the favorable condition on the depth of emplacement, it appears that the probabilities of erosion causing a loss of isolation are lower than those considered credible in EPA regulations (40 CFR Part 191).

Summary of the comparative evaluation

At all the sites, the underground repository can be placed deep enough to protect it from erosional processes acting on the surface. The predicted rates of erosion are low at all five sites. All waste-emplacement horizons are too deep for credible geomorphic processes to adversely affect the performance of the repository. Although the rates of erosion vary from site to site, the variation is not significant. None of the sites is expected to erode to such an extent that the waste would be uncovered during the first 1 million years. It is also very unlikely that erosion at any of the sites would result in releases of radionuclides during the first 10,000 years. Therefore, all sites are approximately equivalent with respect to the erosion guideline.

7.2.1.6 Dissolution

The qualifying condition for postclosure dissolution is as follows:

> The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution

within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-6), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition: evidence of host-rock dissolution during the Quaternary Period. This major consideration is influenced by several contributing factors, such as the solubility of the host rock under nonextreme geologic and hydrologic conditions, unusual ground-water chemistry, and evidence of significant dissolution during the Quaternary Period. The consideration is directly related to the qualifying condition through concern about the disruption of the natural and engineered barriers by the dissolution of the host rock. Such disruption would result in the potential for exceeding the radionuclide-release limits set by the NRC and the EPA. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major consideration

The Davis Canyon site is 16 kilometers (10 miles) from the nearest known or potential dissolution feature. Although data on the rate of migration of dissolution fronts in the Paradox Basin are not available, the rates estimated for other basins suggest that a dissolution front would not reach the site for at least 10,000 years. However, it should be noted that the use of such an extrapolation technique increases the level of uncertainty in this estimate. Other known and suspected dissolution features in the area include the Lockhart Basin, 19 kilometers (12 miles) to the north; Beef Basin, 22 kilometers (14 miles) to the southwest; the Needles Fault Zone, 18 kilometers (11 miles) to the west; and the Shay/Bridger Jack/Salt Creek graben system, 16 kilometers (10 miles) to the south. Data derived from field mapping and geophysical logging near the site have not revealed features that would indicate Quaternary dissolution. However, the saline ground waters of the overlying Honaker Trail Formation and the underlying Leadville Formation are thought to indicate past or continuing dissolution of the salt in the Paradox Formation.

The Deaf Smith site is somewhat further from active dissolution fronts than Davis Canyon. Dissolution at or above the repository level is known to occur 103 kilometers (64 miles) to the west, 29.8 kilometers (18.5 miles) to the north and 118 kilometers (73 miles) to the east of the Deaf Smith site. The rates of migration for these dissolution fronts have been calculated from data on the level of salinity in streams. These data suggest that the most rapid rate of migration for the dissolution fronts is 0.98 meter (3.2 feet) per year for the eastern front, while the northern front is migrating at a rate of 0.0008 meter (0.0024 foot) per year. The rate of dissolution for the western front is expected to be even lower. These calculations are based on the assumption that the dissolution front is uniform, which could underestimate the actual rate of dissolution. Within the basin, interior dissolution is evident in the uppermost salt sequence beneath the High Plains aquifer, as indicated by data from dissolution wells. However, the rate of

Table 7-6. Guideline-condition findings by major consideration--dissolution[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.	P	P	P	P	P
Potentially adverse condition					
Evidence of dissolution within the geologic setting--such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse--such that a hydraulic interconnection leading to a loss of waste isolation could occur.	P	P	NP	P	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are associated with one major consideration: effects of dissolution processes on waste isolation.

dissolution is very slow and has been estimated to be 0.000064 meter (0.000021 foot) per year. No dissolution fronts near the Deaf Smith site or in the interior basin are expected to intersect the repository horizon in less than 100,000 years.

The rock at the Hanford site consists of minerals that are not readily soluble, and significant dissolution leading to radionuclide releases from the site is not considered credible. It is highly unlikely that dissolution will occur along fractures within the repository during or after the thermal phase to the extent that the permeability of the fracture system will increase. The permeability of the fracture system will probably decrease because of the alteration of glass and the formation of clays and zeolites within the fractures.

The Richton site has no topographic depressions over the salt dome, and limited data suggest that the Tertiary sediments overlying the dome are laterally continuous. There are two relatively small, closed circular depressions just off the eastern flank of the dome that appear to be the result of near-surface processes; however, at this time, their origin is uncertain. Samples of ground water from a shallow fresh-water aquifer reveal possible saline anomalies on the south side of the dome (downgradient of the dome). These anomalies were identified on the basis of a very limited number of boreholes; therefore, the origin of the high salinity level in the water of the upper aquifer is unknown at this time. Possible origins for the salinities include salt-dome dissolution, variability of aquifer conditions, and artificial contamination.

The Yucca Mountain site is composed of rock whose minerals are not readily soluble, and significant dissolution leading to radionuclide releases from the site is not considered credible. It is highly unlikely that dissolution will occur along fractures within the repository during or after the thermal phase to the extent that the permeability of the fracture system will increase.

Summary of comparative evaluation

Hanford and Yucca Mountain are the most favorable sites for the dissolution guideline because the host rocks and surrounding unit consist of minerals that are not readily soluble.

The Davis Canyon, Deaf Smith, and Richton sites are less favorable. Available data suggest that dissolution probably occurred at each salt site during the Quaternary Period, but the rates of dissolution are too low to lead to a loss of waste isolation. There is, however, considerable uncertainty associated with these rates because of the limited data base for each site.

7.2.1.7 Tectonics (postclosure)

The qualifying condition for postclosure tectonics is as follows:

> The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-7), one major consideration is identified that influences the favorability of the sites with respect to the qualifying condition. This major consideration concerns estimates and projections of igneous activity and tectonic processes over the next 10,000 years and the effect of these processes on radionuclide releases. It is directly related to the qualifying condition through the evaluation of radionuclide releases attributed to potential tectonic phenomena. It is derived from the favorable condition and the six potentially adverse conditions.

The contributing factors for this major consideration include evidence of tectonic or igneous activity during the Quaternary Period, the likelihood for the next 10,000 years of tectonic and igneous events that could alter the regional ground-water-flow system, the historical record of seismicity, the correlation of earthquakes with tectonic features, evidence of Quaternary tectonic processes (especially at the repository site), and the potential effects of tectonic and igneous events on the repository. The rates of igneous and tectonic activities cannot be evaluated individually; these conditions must be evaluated together to determine their impact on the total isolation system, and therefore only one major consideration was identified for this guideline. A summary of the evaluation for each site follows.

Evaluation of sites in terms of the major considerations

In the geologic setting of the Davis Canyon site, Quaternary uplift has averaged less than 0.60 meter (2 feet) per 1,000 years. Although no surface faults have been identified at the site, Quaternary faulting may be present in the vicinity of the site at Shay Graben. These faults, however, may be related to salt dissolution rather than tectonism. These faults do not trend toward the site, nor have preliminary investigations shown any surface faults at the site. No known igneous activity has occurred within the geologic setting in the last 2 to 3 million years. No earthquakes have been observed within the site, but the historical record of seismicity is limited. The Paradox Basin has been classified as a relatively low seismic hazard region. However, there is a possibility that the south Shay Graben fault may be capable of producing an earthquake larger than any observed in the geologic setting. The geologic record does not show that any natural impoundments on

Table 7-7. Guideline-condition findings by major consideration-tectonics (postclosure)[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition 1					
The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than 1 chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.	P	P	P	P	NP
Potentially adverse condition 1					
Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.	P	P	P	P	P
Potentially adverse condition 2					
Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.	P	NP	P	NP	P
Potentially adverse condition 4					
More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.	NP	NP	NP	NP	NP
Potentially adverse condition 5					
Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.	NP	NP	NP	NP	NP
Potentially adverse condition 6					
Potential for tectonic deformations—such as uplift, subsidence, folding, or faulting—that could adversely affect the regional ground-water flow system.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are associated with one major consideration: nature and rates of tectonic processes and igneous activity that may affect waste isolation.

the scale necessary to cause large changes in the regional ground-water-flow system occurred in the geologic setting. Regional uplift will not affect the physical integrity of the repository and will be too small to significantly modify ground-water-flow systems in the next 10,000 years. Reactivation of the basement faults beneath the site is possible, but it is doubtful that displacements large enough to propagate these features through the ductile rocks of the Paradox Formation would occur in the next 10,000 years. In general, tectonic data indicate that the likelihood of disruptive tectonic events is very low and suggest that igneous or tectonic activity at the Davis Canyon site could not lead to radionuclide releases greater than regulatory limits after repository closure.

At the Deaf Smith site, data were collected by reviewing published literature and conducting preliminary field surveys. There is no evidence of igneous activity during the Quaternary Period at the Deaf Smith site. The nearest igneous activity during the Quaternary occurred about 160 kilometers (99 miles) west of the site, outside the geologic setting. Quaternary tectonic processes were probably negligible near the site. Regional uplift or subsidence is not recognized, but the possibility that these processes occurred on a small scale during the Quaternary Period has not been ruled out. The site is located in a region of low seismicity. Quaternary faulting and folding of a tectonic (or seismogenic) nature are not recognized in the Palo Duro Basin. No large damaging earthquakes have occurred in the geologic setting during the period of the historical record. The terrain of the site and its vicinity is flat and would not be affected by natural phenomena large enough to cause large-scale surface-water impoundments. Small amounts of uplift or subsidence are not likely to adversely affect the regional ground-water flow over the next 10,000 years. Some uncertainty exists because site-specific information on subsurface faulting has yet to be fully evaluated. However, the likelihood of disruptive tectonic events affecting any releases of radionuclides after closure is thought to be extremely low.

For the Hanford site, preliminary estimates of the rates of tectonic deformation suggest low long-term average rates of strain. Volcanism in the Columbia River Basalt Group ceased approximately 6 million years ago. Although Quaternary volcanism has occurred in the western Columbia Plateau, it appears to be more closely related to volcanism in the Cascades. There are faults within the Columbia Plateau that are interpreted to have been active during the Quaternary Period. Seismic activity has been monitored at Hanford since 1969, but detailed seismic monitoring at the proposed repository depth is only beginning. Some of the faults in the geologic setting could be associated with earthquakes larger than the historical maximum. Available data do not permit the precise determination of slip and recurrence rates for specific faults; however, on the basis of current knowledge, earthquakes near the site would be relatively small, with long recurrence rates for larger events (a magnitude greater than about 5.5). Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner that suggests unmapped, buried, or steeply dipping faults occur in the Pasco Basin. It does not appear that natural phenomena or tectonic deformations would create large-scale surface-water impoundments that would cause significant changes in the regional ground-water-flow system.

Although the rate of deformation at Hanford does not appear to be significant enough to affect the release of radionuclides, there is considerable uncertainty because microearthquake swarms have been observed in the basalt during the past 16 years, though no swarms have occurred recently in the basalt at the site. The potential effects of microearthquake swarms on system performance (including the ground-water-travel time, system geochemistry, and waste-package integrity) suggest that the likelihood of tectonic phenomena affecting the site's ability to isolate waste over the next 10,000 years is very low.

At the Richton site, the evidence from the geologic setting suggests that no igneous activity and only minor tectonic activity occurred during the Quaternary Period. The principal active tectonic process during the Quaternary Period is regional uplift. Diapirism does not appear to have occurred at the Richton Dome. There has been no igneous activity in or near the Mississippi salt basin since the Cretaceous Period (about 60 million years ago). There is no evidence of Quaternary seismogenic fault movement in the geologic setting, and the infrequent seismic activity that does occur is low in magnitude. The nearest known earthquake epicenter is 75 kilometers (45 miles) away. The region has no large surface-water impoundments from tectonic or igneous processes. Projections of uplift based on Quaternary data suggest that its rates are too low (0.01 meter per 1,000 years) to adversely affect the regional ground-water-flow system during the next 10,000 years. On the basis of the Quaternary record, future tectonic processes and events are not likely to be disruptive, and the likelihood of disruptive tectonic events is very low.

Much of the background data for the evaluation of tectonic activity at Yucca Mountain has been developed through many years of study related to nuclear weapons testing at the Nevada Test Site. The assessment of future tectonic processes is uncertain and difficult for Yucca Mountain. There is evidence that volcanism and faulting occurred in the vicinity of the site during the Quaternary Period. In addition, the seismicity of the region is not understood well enough to rule out the possibility of large earthquakes (magnitude of 7 or greater) occurring in the region after closure. According to previously published estimates of recurrence intervals, regional return periods for earthquakes with a magnitude of 7 or greater are probably on the order of 25,000 years. At present, a preliminary conclusion could be made that the north-trending faults at the site should be considered potentially active, even though the absence of fault scarps and the low level of seismic activity suggests they are not active. The geologic setting of Yucca Mountain is not yet well enough understood to preclude the possibility of future earthquakes larger than those that have occurred at or near the site.

The formation of large-scale surface-water impoundments by natural phenomena like landslides, subsidence, or volcanic activity is not likely in the area of Yucca Mountain. There is also a very small potential for tectonic deformation at the site of a magnitude that would affect the regional ground-water flow. On the basis of available information, it appears unlikely that volcanic events or future tectonic processes and events would adversely affect the containment and isolation capabilities of the repository, although numerical probabilities have not been determined for most processes. This conclusion is based on the moderate (although uncertain) probabilities of tectonic events, the likelihood that the ground-water travel time is long and the flux is low, the selection of waste-emplacement areas away from recognizable fault zones, the structural integrity of the waste package, and the geochemical characteristics of the site.

Summary of comparative evaluation

The most favorable sites with respect to the postclosure tectonics guideline are Davis Canyon, Deaf Smith, and Richton. Although the Davis Canyon site appears to have a higher rate of tectonic activity near the site (as indicated by potential Quaternary faulting), there is a very low likelihood that tectonic events could lead to releases at any of these sites, and none show evidence of igneous activity in the geologic setting. Active faulting may also be present in the geologic setting of Davis Canyon, but no surface faults have been identified at the site, and seismic and geologic evidence qualitatively suggests that the region will be stable over the long term. The available data suggest that there is very little likelihood of disruptive tectonic or igneous events during the next 10,000 years at all three sites. Both the Deaf Smith and the Richton sites have experienced no igneous activity and insignificant tectonic activity during the Quaternary Period. There are no known Quaternary seismogenic faults in either geologic setting, and the level of seismicity at both sites appears to be very low.

Hanford is slightly less favorable than the salt sites for this guideline. There is some evidence that deformation is occurring within the basalts at Hanford, but the pattern of deformation qualitatively matches the pattern of known seismicity, suggesting that earthquakes and rupture planes would be relatively small and recurrence times generally long. There is some uncertainty because microearthquake swarms in the basalts have been observed during the past 16 years. In addition, no microearthquakes (nonswarm) have been observed within the repository site at the depth of the basalts. The likelihood of tectonic phenomena affecting the ability of the site to isolate waste over the next 10,000 years is very low.

Yucca Mountain is less favorable than the other sites. Quaternary faults are present within 1 to 6 kilometers of the site. Their effects on the potential for ground motion and on ground-water flow need to be assessed. The likelihood of volcanism may be high enough for volcanism to be considered in performance assessment. However, the effects of igneous and tectonic activity on system performance (qualifying condition) at Yucca Mountain are not expected to lead to radionuclide releases greater than those allowed by regulation. This assessment accounts for ground-water flux and travel time, waste emplacement away from recognized fault zones, the structural integrity of the waste package, and the geochemical characteristics of the site.

7.2.1.8 Human interference

The potential for human interference after the closure of the repository requires an analysis of (1) the natural resources at or near a site, addressing historical, current, and future exploration for, and uses of, these resources, and (2) site ownership and control. Evaluations of these two separate technical guidelines are provided below.

7.2.1.8.1 Natural resources

The qualifying condition for natural resources is as follows:

> This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in §960.4-1.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-8), three major considerations are identified that influence the favorability of the sites. In decreasing order of importance, they are (1) evidence of subsurface mining, resource extraction, and drilling sufficient to affect containment and isolation; (2) potential for foreseeable human activities that could affect containment and isolation; and (3) potential for postclosure intrusion for resource extraction. Although the major considerations are listed in decreasing order of importance, the differences in their importance are small, particularly between the second and the third considerations.

Evaluation of the sites in terms of the major considerations

Evidence of subsurface mining, resource extraction, and drilling sufficient to affect containment and isolation. This consideration assesses the potential effects on waste containment and isolation of existing mines and drillholes within the site. Contributing factors include the presence of active and closed mines as well as evidence of deep drilling and related resource extraction. This consideration is derived from the second and the third potentially adverse condition and is the most important major consideration because existing mines or drill holes could act as pathways for radionuclide migration to the accessible environment. A summary of the evaluation for each site follows.

At the Davis Canyon site, existing uranium mines extend to a maximum depth of 11 meters (35 feet) and are restricted to the Chinle Formation, which has been eroded from most of the repository operations area. These existing excavations are not thought to be extensive enough or deep enough to affect the repository. No drilling is known to have occurred within the site. The nearest hydrocarbon-exploration borehole of appreciable depth is 8 kilometers (5 miles) from the boundary of the repository operations area.

There is no subsurface mining at the Deaf Smith site. There are no known wells that penetrate below the Ogallala aquifer and no known hydrocarbon-exploration holes at the site. Deep drilling at the site is unlikely to have occurred in the past.

Table 7-8. Guideline-condition findings by major consideration--natural resources[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: EVIDENCE OF SUBSURFACE MINING, RESOURCE EXTRACTION, AND DRILLING SUFFICIENT TO AFFECT CONTAINMENT AND ISOLATION					
Potentially adverse condition 2					
Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL FOR FORESEEABLE HUMAN ACTIVITIES SUFFICIENT TO AFFECT CONTAINMENT AND ISOLATION					
Potentially adverse condition 5					
Potential for foreseeable human activities such as ground-water withdrawal, extensive irrigation, sub-surface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments—that could adversely change portions of the ground-water flow system important to waste isolation.	NP	NP	P	NP	NP
MAJOR CONSIDERATION 3: POTENTIAL FOR POSTCLOSURE INTRUSION TO EXTRACT RESOURCES					
Favorable condition 1					
No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.	NP	NP	NP	NP	P
Favorable condition 2					
Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.	P	P	NP	P	NP

Table 7-8. Guideline-condition findings by major consideration--natural resources[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: POTENTIAL FOR POSTCLOSURE INTRUSION TO EXTRACT RESOURCES (Continued)					
Potentially adverse condition 1					
Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.	P	P	P	P	NP
Potentially adverse condition 4					
Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.	NP	NP	NP	NP	NP

[a] Key: NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

Current and past mining or extraction activities in the area of the Hanford site include some quarrying for sand and gravel as well as a small natural gas field that ended production in 1941. The quarries are excavated pits that are generally less than 18 meters (60 feet) deep. The gas field was located approximately 11 kilometers south of the site. No other current or past production of hydrocarbons has been reported within 100 kilometers of the larger Hanford Site. Recent hydrocarbon exploration in the Columbia Plateau has been focused on the sedimentary sequence beneath the basalt; wells drilled to date have been noncommercial, but some natural gas has been recovered. Although methane has been found as dissolved gas in ground water from the Grande Ronde Formation beneath the site, the hydrocarbon potential for this area is speculative at best. Boreholes drilled near the site for purposes other than repository-site evaluation are significantly shallower than the candidate repository horizon and would not affect waste containment or isolation.

At the Richton site, there is no evidence of boreholes, shafts, or other excavations that penetrate the repository horizon within the salt dome. Eight mineral-exploration boreholes have been drilled into salt with a maximum reported penetration of 6.4 meters (21 feet). Within 10 kilometers (6.2 miles) of the dome, 34 sulfur-exploration wells and 32 petroleum-exploration wells have been drilled. The water wells within the area are shallow (less than 366 meters (1,200 feet)) and are drilled into the upper aquifer. The closest fluid-injection wells are at least 4.8 kilometers (3 miles) from the flank of the dome. Waste containment and isolation are not expected to be significantly affected by the presence of shallow boreholes or the potential for increased dissolution associated with the petroleum-exploration wells on the sloping flank of the dome.

There has been no subsurface mining or extraction of resources at Yucca Mountain. There is little likelihood that unknown excavations exist at the site other than shallow prospecting pits. Before the repository investigations began, one borehole had been drilled 7 kilometers (4 miles) southeast of the site (water well J-13), and another had been drilled approximately 15 kilometers (9 miles) to the northeast (water well J-12). There has been no drilling at Yucca Mountain for purposes other than repository-site evaluation.

<u>Potential for foreseeable human activities that could affect containment and isolation</u>. Factors contributing to this consideration include the potential for ground-water withdrawal, irrigation, the injection of fluids, underground pumped storage, and large-scale surface-water impoundments. Changes to the site's ground-water system can directly affect the releases of radionuclides to the accessible environment. This consideration is derived from the fifth potentially adverse condition and is the second most important major consideration. Changes to the site's ground-water system can directly affect the releases of radionuclides to the accessible environment. This consideration is not as important as the first major consideration because it is based on projected, more speculative human activities that may affect isolation, whereas the first consideration is based on existing evidence of resources that could affect isolation.

In assessing the likelihood of postclosure intrusion, the DOE will consider the estimated effectiveness of the permanent markers and records required by NRC regulations in 10 CFR Part 60. Human-intrusion events are considered to be credible only if it is assumed that the monuments provided for in the NRC regulations are permanent enough to serve their intended purpose. Thus, in evaluating this major consideration, the environmental assessments have qualitatively considered the effectiveness of markers and records in reducing the likelihood of human intrusion in the controlled area. A summary of the evaluation for each site follows.

Because of limited potable water and resources within and near the Davis Canyon site, the potential for foreseeable human activities to adversely affect the ground-water-flow system is expected to be very low.

At the Deaf Smith site, good-quality ground water that is suitable for irrigation and domestic use is drawn entirely from the Ogallala aquifer. The ongoing depletion of the Ogallala aquifer will not reverse the downward flow potential at the site. The potential for the subsurface injection of fluids is considered to be low because of the low potential for petroleum development in the future.

At the Hanford site, there is a potential for ground-water withdrawal for irrigation. Insufficient data are available to determine whether such human activities could adversely change portions of the ground-water flow system that are important to waste isolation. However, it is believed that, even if portions of the ground-waste-floor system were to change, there would be no significant effect on waste isolation itself.

At the Richton site, the potential to adversely affect the ground-water-flow system is expected to be very low. Potential human activities are very unlikely to affect ground-water travel through the salt stock; this includes activities that may change fresh-water aquifers. The likelihood of pumped storage in the controlled area is also expected to be very low, considering the permanent markers and records.

Although potable ground water is present at the Yucca Mountain site, future generations are not likely to drill for water from the top of Yucca Mountain, because it would be easier to drill for water in the surrounding areas. Because isolation depends primarily on the thick unsaturated zone, withdrawal of water outside the controlled area would not adversely affect the ground-water system important to isolation.

<u>Potential for postclosure intrusion to extract resources</u>. This consideration includes estimates of, and the potential for, postclosure intrusion for resource extraction. Contributing factors include the presence or indication of resources (including water) at the site, their value, scarcity, and depth, as well as their availability from other sources. This condition is derived from the first and the second favorable conditions and the first and the fourth potentially adverse conditions. This consideration is third in importance because the potential for resources is based on speculative or indirect evidence. Nevertheless, this consideration is significant because exploration for, or the extraction of, resources can create pathways for radionuclides to reach the accessible environment. A summary of the evaluation for each site follows.

Uranium and vanadium deposits are present in the vicinity of the Davis Canyon site, and some production has occurred at the site itself; however, the uranium resources at the site are believed to be less significant than those in other parts of southeastern Utah. In addition, commercial-grade underground potash deposits are present in the vicinity of the site, but they may not be economic because they are located at excessive depths and are less extensive than deposits in other parts of Utah. Small amounts of sand, gravel, and potable water have been extracted in the vicinity of the site. None of these resources has greater potential within the area of the site than outside it. Potential hydrocarbon resources are believed to be significantly smaller within the site than in similar areas outside the site. The ground-water is of poor quality, with the total dissolved solids exceeding 10,000 parts per million.

At the Deaf Smith site, ground water is being extracted from the Ogallala aquifer. The use of this water resource does not pose a threat to the long-term integrity of the repository. Ground water along the likely pathways of radionuclide travel is not suitable for human consumption because it contains dissolved solids at concentration exceeding 10,000 parts per million. The hydrocarbon potential at the site is not considered to be significant, but exploration for oil and gas in the future cannot be discounted. No other mineral resources, such as uranium and construction aggregates, are present in unique quantities at the site. The bedded salt may be considered a halite resource. There are no known concentrations of naturally occurring materials that are not widely available from other sources.

At the Hanford site, there are no known metallic or petroliferous resources that have or are projected to have a value great enough to be commercially extractable. However, there are indications that the site contains ground-water resources and natural gas that may be economically feasible to extract in the foreseeable future. Although hydrocarbon source beds may exist beneath the basalt, there is no evidence to date of significant concentrations of any naturally occurring resources that are unique to the site.

The Richton Dome is the largest of 35 shallow salt domes in the Mississippi salt basin. Because of its size and depth, it is an excellent candidate for underground storage. The purity of the salt (91 percent sodium chloride) also indicates that the dome may be a candidate for salt extraction by solution mining or conventional mining methods. In comparison with other shallow salt domes, the potential for storage or salt extraction at the Richton Dome is above average because of its large size, even though salt is widely available from other sources and the dome's potential use as an underground storage facility is not unique. Commercial hydrocarbon resources are not known to exist at the Richton Dome.

Yucca Mountain has no energy or mineral resources for which extraction is feasible in the foreseeable future. No known resources are present at Yucca Mountain that have greater commercial potential than those in other areas in its geologic setting, nor is there evidence of any significant concentration of potentially valuable resources at Yucca Mountain. The mineral-resource potential of the Yucca Mountain site is considered low. The ground water along likely flow paths of radionuclide travel has less than 10,000 parts per million of total dissolved solids.

Summary of comparative evaluation

On the basis of the three major considerations, Yucca Mountain is the most favorable site; Davis Canyon, Deaf Smith, and Hanford are comparable; and Richton is the least favored site. The differences among the sites, however, are small. This judgment is based on the fact that there is no evidence at any of the sites of subsurface mining, extraction, or drilling sufficient to affect containment or isolation. There is also no evidence at any of the sites of a significant or unique concentration of any naturally occurring mineral or energy resources. It is expected that the use of permanent markers and records will reduce to very low values the likelihood of human intrusion within the controlled area at each of the sites.

The likelihood of any resource occurring at the Yucca Mountain site appears to be very low. The potential use of the deep aquifer outside the controlled area will not affect containment and isolation.

The Davis Canyon, the Deaf Smith, and the Hanford sites are approximately equal in favorability on the basis of the speculative potential for resources. There is a very small potential for the use of the shallow aquifer outside the controlled area at the Hanford site to affect the ground-water-flow system important to isolation.

Richton Dome is the least favorable site because of the speculative potential for resources, the possibility of undetected boreholes, and the potential for using the dome for underground pumped storage.

7.2.1.8.2 Site ownership and control

The purpose of the postclosure guideline on site ownership and control is to help ensure that the repository can function far into the future without adverse human interference. This guideline specifies that the DOE, in accordance with the requirements of the 10 CFR Part 60, is to obtain ownership of, and surface and subsurface rights to, land and minerals within the controlled area of the repository. A similar guideline on site ownership is provided for the preclosure period. The purpose of the preclosure guideline is to ensure that surface and subsurface activities during repository operation will not be likely to lead to radionuclide releases greater than those allowed by applicable regulations.

The DOE has determined that the necessary land area and controls are the same for both the postclosure and the preclosure periods at the five nominated sites. Whichever site is selected, the DOE must obtain ownership as well as surface and subsurface rights before commencing preclosure activities; there is no basis for distinguishing among the sites on their site ownership and control status at the beginning of the postclosure period. Therefore, all sites are considered to be equally favorable for this guideline.

7.2.2 POSTCLOSURE SYSTEM GUIDELINE

The results of preliminary system-performance assessments are described in Section 6.4.2 of each environmental assessment and briefly reviewed here. These preliminary assessments are based on limited geologic, hydrologic, and geochemical information, preliminary conceptual models, and relatively simple analytical techniques. The DOE is therefore not yet prepared to provide assurance that regulatory criteria will be met at any of the sites. These preliminary assessments do, however, appear adequate for evaluating the sites against the postclosure system guideline. However, the different approaches to the evaluation of performance, the preliminary nature of these assessments, and the uncertainties in the parameters on which the analyses are based all limit the ability to compare the sites in the manner required by the implementation guidelines for site comparisons that will support the recommendation of a site for development as a repository. To provide a comparative context for understanding the postclosure system guideline evaluation in Chapter 6, a brief discussion of the evaluation of each of the sites with respect to each of the capabilities addressed by the guideline is presented below.

The guideline addresses the following capabilities of the geologic setting at a site:

1. The capability of the geologic setting at the site to allow for the physical separation of the waste from the accessible environment after closure in accordance with the requirements of the EPA standard in 40 CFR Part 191, Subpart B, as implemented by 10 CFR Part 60.

2. The capability of the geologic setting at the site to allow for the use of engineered barriers to ensure compliance with the requirements of the EPA and the NRC. Two requirements are pertinent here: (1) the time of substantially complete containment (i.e., a period between 300 and 1,000 years); and (2) the limit on the rate of radionuclide releases from the engineered-barrier system (i.e., one part in 100,000 per year of the individual radionuclide inventory or one part in 100,000 per year of the total inventory calculated to be present at 1,000 years after repository closure, whichever is greater).

<u>Capability for waste isolation</u>. The results of the preliminary assessments indicate that the EPA standards would be met at all of the sites. For example, the mean time of ground-water travel from the repository to the accessible environment is expected to be much longer than 10,000 years at each site. On this basis alone, there is little likelihood of any release for 10,000 years or, more specifically, of exceeding the EPA standard for cumulative releases during this period. In fact, the results of the calculations for the preliminary assessments indicate that releases are likely to be negligible for much more than 10,000 years at each site. Similarly, calculations of ground-water quality indicate that the EPA's ground-water protection and individual-protection requirements will be met at each of the sites. For the Hanford site, the calculations show to a high level of confidence that less than 50 curies of iodine-129 and carbon-14--and no other radionuclides--would be released to the accessible environment in 100,000 years. The calculations for Yucca Mountain indicate that less than 100 curies

of technetium-99 and negligible quantities of any other radionuclide could be released in 100,000 years. The analyses for the salt sites show no release in 100,000 years under expected repository conditions.

Because of the different characteristics of each of the sites, different approaches to the performance analyses and varying levels of conservatism have been used for each site. For example, the constraint on release due to the slow degradation of the waste form was not taken into account in the analysis of the Hanford site. The analysis of the Yucca Mountain site does not consider the spatial distribution of waste packages throughout the repository, but assumes that the release occurs from a single location in the host rock. Transport and retardation in the saturated zone are not considered in these analyses as well. The margin of conservatism resulting from such assumptions in each case is not known at present. However, it is believed to be sufficient to compensate for the uncertainties in the site data. The preliminary performance assessments do not provide evidence to support a finding that any of the sites would not adequately isolate the waste from the accessible environment.

Requirements for engineered-barrier performance. Preliminary assessments of the engineered-barrier system indicate that this system would meet the regulatory performance objectives at all sites. For example, the analyses of waste-package performance indicate that the container lifetime is expected to exceed the 300- to 1,000-year requirement for substantially complete containment at each site. The expected container lifetime for the Hanford site exceeds 6,000 years. The analysis of the container under the conditions of the Yucca Mountain site gives a lower-bound estimate of 3,000 years and an expected lifetime of 30,000 years. At the salt sites, the lifetime of the container is calculated to be even longer, because it is expected that sufficient water will not be available to cause corrosion failure of the waste package.

For each site, the calculations of the rate of radionuclide release after the failure of the waste package suggest that the criterion for the rate of release from the engineered-barrier system would not be exceeded. At the Hanford site, the release rate for most radionuclides would be well below the regulatory criterion because of the diffusion-limited transport and the limited solubility of these radionuclides in the ground water at the site. For the few radionuclides that are highly soluble, the calculated release rates are less than 4 percent of the release-rate limit.

Without taking into account the solubility of the radionuclides themselves, the fractional release rate calculated for the Yucca Mountain site is 2.5×0^{-9} per year, well below the limit of 1×10^{-5} per year, because of the low rate expected for waste-form dissolution. At the salt sites, since it is expected that the waste packages will last indefinitely, the rate of radionuclide release from the engineered-barrier system is expected to be zero.

Extremely conservative assumptions were used in making these estimates. For example, in all cases the calculations are for releases from the waste package, which is expected to provide an upper bound to the release from the total engineered-barrier system. In addition, any containment offered by the spent-fuel cladding was not taken into account in any of the analyses. In the analysis of the salt sites and of the Hanford site, the slow dissolution of the waste form, which can limit the rate of radionuclide release, was not taken into account. In the analyses of the salt sites and of the Yucca Mountain site, it was assumed that all packages fail simultaneously. Again, the degree of conservatism provided by these assumptions is not known at present. However, the analyses appear to be sufficient to indicate that there is no evidence that the performance criteria for the waste package and other engineered barriers would not be met at each of the nominated sites. Furthermore, the available data and the preliminary analyses based on these data have not identified any conditions or features at any of the sites that would prevent these engineered components from meeting the performance requirements.

The different approaches to the evaluation of performance, the preliminary nature of these assessments, and the uncertainties in the parameters on which the analyses are based all limit the ability to compare the sites in terms of these results. In each case the analyses are very simple. The interactions of the various factors that determine subsystem and system performance are not yet known. Finally, the analyses that can be conducted at present are too simple to address the full range of uncertainties that should be addressed in order to provide an adequate comparison of the sites. Therefore, because of the preliminary nature of these performance assessments, it does not appear that a comparison between and among the sites on the basis of the postclosure system guideline is practicable at present.

7.3 COMPARISON OF SITES ON THE BASIS OF PRECLOSURE GUIDELINES

The preclosure guidelines address (1) preclosure radiological safety; (2) the environmental, socioeconomic, and transportation-related impacts associated with repository siting, construction, operation, and closure; and (3) the ease and cost of repository siting, construction, operation, and closure. Both technical and system guidelines are provided for each of these three categories.

7.3.1 PRECLOSURE RADIOLOGICAL SAFETY

7.3.1.1 Technical guidelines

There are four technical guidelines on preclosure radiological safety: (1) population density and distribution, (2) site ownership and control, (3) meteorology, and (4) offsite installations and operations. The objective of these guidelines is to protect the health and safety of the public and the workers at the repository by keeping exposures to radiation within the limits prescribed by regulations. This section presents a comparative evaluation of the five nominated sites against these guidelines.

7.3.1.1.1 Population density and distribution

The qualifying condition for population density and distribution is as follows:

> The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in §960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in §960.5-1(a)(1).

<u>Major considerations</u>

On the basis of the qualifying, favorable, potentially adverse and disqualifying conditions for this guideline (Table 7-9), two major considerations are identified that influence the favorability of the sites with respect to population density and distribution. These major considerations are (1) remoteness of the site from highly populated areas and (2) the population density at the site, near the site, and in the general region of the site. These major considerations are of equal importance and are in turn influenced by several more-specific contributing factors, which are discussed below.

<u>Evaluation of the sites in terms of the major considerations</u>

<u>Remoteness</u>. The remoteness of a site is measured by its distance from highly populated areas of 2,500 people or more, or from an area with 1,000 or more persons within 1 square mile. This major consideration is derived from the second favorable condition and the second potentially adverse condition (see Table 7-9). It relates to the qualifying condition in that the potential for radiation exposure increases with proximity to population concentrations. The second favorable condition refers to the remoteness of the site from highly populated areas, and the second potentially adverse condition addresses the proximity of the site to populated areas and areas with at least 1,000 individuals in an area that is 1 mile by 1 mile. The two contributing factors related to this major consideration are (1) the air distance of the site from population concentrations and (2) the size of those concentrations. Specifically, the closer a site is to highly populated areas, and the larger such population concentrations are, the less favorable is the site. A summary of the evaluation for each site follows.

The immediate vicinity of the Davis Canyon site contains no highly populated areas. Moab, with a population of 5,333, is the closest and is approximately 33 miles from the boundary of the controlled area. Moab is also the nearest 1-square mile area with a population of at least 1,000 persons.

The Deaf Smith County site is approximately 17 miles north of Hereford, with a population of 15,853. Hereford is also the nearest area with at least 1,000 persons in a 1-square-mile area.

Table 7-9. Guideline-condition findings by major consideration–population density and distribution[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: REMOTENESS FROM HIGHLY POPULATED AREA					
Favorable condition 2					
Remoteness of the site from highly populated areas.	P	P	P	P	P
Potentially adverse condition 2					
Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile by 1 mile as defined by the most recent decennial count of the U.S. census.	NP	NP	NP	P	NP
MAJOR CONSIDERATION 2: POPULATION DENSITY					
Favorable condition 1					
A low population density in the general region of the site.	P	P	P	P	P
Potentially adverse condition 1					
High residential, seasonal, or daytime population density within the projected site boundaries.	NP	NP	NP	NP	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is <u>not</u> present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

At the Hanford site, Sunnyside is the nearest highly populated area. It has a population of 9,229 and is approximately 15 miles southwest of the site. Sunnyside is also the closest 1-square-mile area with a population of at least 1,000.

At the Richton site, the town of Richton, with a population of 1,205 within a 1 square mile, is adjacent to the proposed boundary of the controlled area. However, the town is 2 miles from the proposed boundary of the surface facilities of the repository. The nearest highly populated area is Petal/Hattiesburg with a population of 49,300; it is 25 kilometers from the boundary of the site.

The Yucca Mountain site is remote from highly populated areas or 1-square-mile areas with a population of at least 1,000. Las Vegas Valley, the nearest highly populated area, is at a distance of approximately 85 miles.

Population density. Population density is evaluated for each site on the basis of density within the projected site boundaries, near the site, and in the general region of the site. For this analysis, "near the site" is defined as being within 10 miles of the site and "in the general region" as being within 50 miles. This major consideration is derived from the first favorable condition and the first potentially adverse condition (see Table 7-9). It relates to the qualifying condition in that a larger number of people are potentially exposed to radioactive releases as the population density in the region of a site increases. The first favorable condition is a low population density in the general region of the site, and the first potentially adverse condition addresses high residential, seasonal, or daytime population density within the projected site boundaries.

In the evaluation of this major consideration, a "low population density" is defined as being less than the average population density of the contiguous United States in 1980, or 76 persons per square mile. This major consideration is also closely related to the third disqualifying condition for this guideline, which is related to emergency planning. Specifically, as population density near the site increases, a more extensive emergency-preparedness plan is required, since protective measures would have to be taken on behalf of a larger number of people in the event of an accident. As the density on the site, near the site, and within the general region of the site increases, the favorability of the site decreases. A summary of the site evaluation for this consideration follows. The site-specific information used in the evaluation is summarized from Section 6.2.1.2 of the environmental assessments for the five nominated sites.

There is no residential or seasonal population within the projected boundaries of the Davis Canyon site. The daytime population is limited to an estimated peak of seven offroad-vehicle users. The onsite population density is therefore far below the national average. About 282 people are estimated to live within 10 miles of the site. The population density in the general region is also far below the national average, at 3.8 persons per square mile.

The Deaf Smith County site is estimated to have 27 residents within its boundaries. The seasonal population density at the site is about seven persons per square mile assuming that the 10,440 migrant workers who were in

Deaf Smith County in 1975 are evenly distributed throughout the county. The combined residential, seasonal, and daytime population density within the site boundary is approximately 10 persons per square mile. The population within 10 miles of the site is estimated to be 1,739. The population density in the general region of the site is 24 persons per square mile.

Although there are no residences or seasonal population at the Hanford site, approximately 700 persons work within the site boundary at any given time, which is equivalent to a population density of 39 persons per square mile. In addition, 4,800 persons are employed in nuclear energy jobs in the vicinity of the site. (However, because these workers receive training in safety and evacuation procedures, they are better prepared than the general public to respond to radiological hazards.) There are approximately 110 people within 10 miles of the site. The population density in the general region of the site is 43 persons per square mile. Federal ownership of the Hanford site reduces the uncertainty associated with future population growth in the area.

The residential population within the proposed controlled area of the Richton site is about 140 people, assuming that there are 50 households with an average size of 2.8 persons. However, there are no residences within the proposed restricted area. Seasonal population fluctuations are expected to be minimal. The daytime population may vary by 100 because a school is located in the southeast portion of the area of the Richton Dome. The population within 10 miles is approximately 4,610. The population density in the general region is 40 persons per square mile.

There are no residences within 6.2 miles of the Yucca Mountain site and no seasonal or daytime populations within the site boundaries. About 5,200 workers are employed at the Nevada Test Site, but most of their activities are conducted on the opposite side of the Nevada Test Site. Because of their experience with nuclear research and testing, workers at the Nevada Test Site are better prepared than members of the general public to deal with radiological hazards. The population density in the general region of the site is approximately 2.5 people per square mile. Federal ownership of the site and the surrounding area reduces the uncertainty of population growth near the site.

Summary of the comparative evaluation

Yucca Mountain is the most favorable site for both major considerations. There are no highly populated areas within 50 miles of the site, and the regional population density is the lowest of all the sites. In addition, there is no residential or seasonal population on or near the site. Davis Canyon is less favorable because it is 33 miles from the highly populated area of Moab, which has a population of 5,333. Nonetheless, the site is remote in comparison with the remaining sites. The population density in the region is also very low--288 people are located within 10 miles of the site. The Hanford site is 15 miles from Sunnyside, which has a population of 9,229. The population density in the region is 43 persons per square mile. These two factors reduce the favorability of the site. There are only 110 residents within 10 miles of the Hanford site, and the 4,800 nuclear energy workers in the vicinity of the site are better prepared than other members of the general public to deal with radiological hazards. The Deaf Smith site is 17 miles from Hereford, which has a population of 15,853. The population density in the region is 24 persons per square mile, and 1,739 people live within 10 miles of the site. The Richton site is proximate to the town of Richton, and 4,610 people live within 10 miles. The population density in the region is 40 persons per square mile. Since there are 140 people and a school within the controlled area, and the highly populated area of Petal and Hattiesburg with a population of 49,300 is 16 miles away, the Richton Dome is the least favorable site for this guideline.

7.3.1.1.2 Site ownership and control

The qualifying condition for site ownership and control is as follows:

> The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in §960.5-1(a)(1).

Major consideration

On the basis of the qualifying, favorable, and potentially adverse conditions of this guideline (Table 7-10), one major consideration is identified that influences the favorability with respect to the qualifying condition. It refers to the kinds of procedures that are available for acquiring land. The major consideration is, in turn, influenced by two contributing factors.

Evaluation of the sites in terms of to the major consideration

The single major consideration for this guideline is the complexity of procedures for acquiring the needed land. This consideration is derived from the favorable condition and the potentially adverse condition (see Table 7-10). The favorable condition addresses whether the DOE has present ownership and control of the site. The potentially adverse condition identifies three means of acquiring land: voluntary purchase-sell, condemnation, and undisputed agency-to-agency transfer. If the DOE is unable to acquire land through one of these means, Congressional action will be required. Each of these land-acquisition mechanisms involves different legal procedures.

There are two ways the DOE can acquire private or State land: voluntary purchase-sell and condemnation. Voluntary purchase-sell means that a landowner voluntarily sells his land to the DOE under the provisions of the Uniform Relocation Assistance and Real Property Acquisition Act of 1970. If a landowner is not willing to sell needed property, the DOE can acquire it by right of eminent domain, or condemnation, under the provisions of the Declaration of Taking Act (40 USC Section 258a). The DOE estimates that about 90 days would be required to condemn privately owned land.

Table 7-10. Guideline-condition findings by major consideration—site ownership and control (preclosure)[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.	NP	NP	P	NP	NP
Potentially adverse condition					
Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.	P	NP	NP	NP	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] Both conditions in this table are related to one major consideration: complexity of procedures for acquiring needed land.

There are two ways that the DOE can obtain jurisdiction over lands that are currently controlled by another Federal agency: agency-to-agency transfers and legislative transfer by Congress. The DOE can acquire land from another Federal agency for up to 20 years under the provisions of the Federal Land Policy and Management Act of 1976. However, to meet the requirements of applicable NRC regulations (10 CFR 60.121), the DOE must obtain permanent jurisdiction over the repository operations area and the controlled area. This permanent withdrawal will require a legislative transfer.

In evaluating the sites against this guideline, the DOE considered what property would be required for repository construction, operation, closure, and decommissioning. Land-acquisition procedures, such as leasing, that might be employed during site characterization were not considered.

Sites for which land will be easier to acquire from a procedural and legal point of view are more favorable. This does not mean that the DOE discounts the socioeconomic impact of acquiring lands, especially privately owned land. The socioeconomic impacts of land acquisition are considered under the socioeconomics guideline. The DOE recognizes, for example, that the condemnation of privately owned lands will disrupt the lives of displaced landowners. Nevertheless, condemnation is legally more straightforward than obtaining the Congressional authorization that would be needed to acquire certain lands under the control of other Federal agencies. The DOE estimates that about 90 days would be required for condemnation, whereas a Federal-land transfer requiring Congressional authorization could take longer and the result could be less certain. Thus, from a strictly procedural point of view, it is easier for the DOE to acquire permanent jurisdiction over State and private lands than Federal lands.

The complexity of procedures for acquiring land depends, in turn, on current ownership (DOE, other Federal agency, State, or private) and the number of landowners. Current ownership determines which acquisition procedures are available. Similarly, the greater the division among landowners (Federal, State, private), the more complicated the overall land-acquisition procedures. A summary of the evaluation for each site follows.

Most of the Davis Canyon site is Federal land controlled by the Bureau of Land Management (BLM), although small portions are owned by the State of Utah and private parties. A Congressional action would be required to obtain permanent jurisdiction over the BLM portion of the site. Although the DOE would prefer to acquire State and private lands by voluntary purchase-sell agreements, the land could be acquired by condemnation if necessary.

The Deaf Smith site is privately owned, and ownership is divided among at least eight parties. The Richton site is also on private lands with ownership divided among many parties. Although the DOE would prefer voluntary purchase-sell agreements with the current owners, the land can be acquired by condemnation.

The DOE controls all surface and subsurface rights to the Hanford site and the surrounding area. The DOE would not have to acquire any land for a repository at Hanford.

The Federal land of the Yucca Mountain site is under the control of three agencies: the DOE, the BLM, and the Department of Defense (the Air Force). Congressional action would be required to permit a permanent transfer of land from the BLM and the Air Force to the DOE, but the action is not expected to be disputed by these agencies.

Summary of the comparative evaluation

The Hanford site is the most favorable for the preclosure guideline on site ownership and control because the DOE has control over the entire site. The Deaf Smith and the Richton sites are on private land that can be acquired by voluntary purchase-sell agreements or the right of eminent domain. Control over the Yucca Mountain site is divided among three Federal agencies, and Congressional action would be required to permit a permanent transfer to the DOE. The Davis Canyon site is the least favorable because the ownership of land is divided among the BLM, the State of Utah, and private parties, and a combination of actions (voluntary purchase-sell agreements, condemnation, and Congressional action) would be required to acquire the needed land.

7.3.1.1.3 Meteorology

The qualifying condition for meteorology is as follows:

> The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in §960.5-1(a)(1).

Major considerations

The qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-11) led to the identification of two major considerations that influence favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) conditions that affect the transport of radionuclide releases in the atmosphere and the significance of transport, and (2) extreme weather phenomena. The transport consideration addresses prevailing meteorological conditions, while the extreme weather consideration addresses specific episodes. These major considerations are influenced by several contributing factors which are discussed below.

Evaluation of the sites in terms of the major considerations

Conditions that affect transport and the significance of transport. This major consideration addresses meteorological conditions that affect the transport of airborne radionuclide releases to unrestricted areas where the general public might be exposed. Contributing factors are the dispersion characteristics of the atmosphere, wind speed and direction, episodes of stagnation, atmospheric mixing levels, the terrain, and the locations of nearby populations. This is the most important major consideration under this guideline because the potential for a preferential transport of radionuclides

Table 7-11. Guideline-condition findings by major consideration—meteorology[a,b]

Condition[c]	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
Favorable condition					
Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposures to any member of the public in the vicinity of the repository.	NP	P	P	P	P
Potentially adverse condition 1					
Prevailing meteorological conditions such that radioactive emissions from repository operation and closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.	P	P	P	P	NP
Potentially adverse condition 2					
History of extreme weather phenomena—such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms that could significantly affect repository operation or closure.	P	P	NP	P	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

[c] All of the conditions in this table are related to one major consideration: conditions that affect transport and the significance of transport.

directly affects a site's ability to meet the requirements of the preclosure system guideline on radiological safety. In terms of the significance of transport, the doses delivered to the maximally exposed person beyond the boundaries of the site are estimated to be well within the limits of 40 CFR 191 for each site. The estimate is based partly on estimates of radionuclide releases to unrestricted areas; at each site, these releases would be within the limits specified by the NRC in 10 CFR Part 20. A summary of the evaluation for each site follows.

For the Davis Canyon site, representative offsite data indicate that relatively high mixing heights and moderate average wind speeds prevail. Dispersion may be hampered by the rugged surrounding terrain, and local inversions (about 39 episode-days per year) can cause air to be trapped in valleys. The prevailing wind directions at the site are from the southwest. The only population concentration in the downwind direction within 50 miles of the site is La Sal Junction, which is 19 miles away.

For the Deaf Smith site, representative offsite data indicate that neutral atmospheric stability conditions and high average wind speeds predominate, resulting in relatively good dispersion conditions. The prevailing mixing level, the infrequent occurrences of stagnation episodes, and the generally flat terrain at the site also favor dispersion. The prevailing wind directions at the site are from the southwest. The nearest population concentrations in the downwind direction are Masterson and Exell, which are both about 50 miles away.

The data recorded at the Hanford Meteorological Station indicate that dispersion conditions at the Hanford site are generally good. Favorable conditions include moderate average wind speeds and deep mixing levels. The prevailing wind directions are from the northwest. The Tri-Cities area (Richland, Kennewick, and Pasco) is 22 to 28 miles from the site in the predominant downwind direction.

Representative offsite data used for the analysis indicate that atmospheric stability and average wind-speed conditions favor fair to good dispersion. Mixing-level heights, the relative infrequency of stagnation episodes, and the flat to rolling terrain also favor good dispersion. The prevailing wind directions at the site are from the south and southeast. The nearest large population concentrations located in the downwind direction are Laurel and Bay Springs, which are 24 and 40 miles, respectively, from the site.

Meteorological data recorded at Yucca Flat indicate that wind velocities, atmospheric stability, and mixing heights at the site should provide effective atmospheric dispersion. Topographic conditions should also favor dispersion. The nearest population concentrations are Beatty, which is 19 miles to the west, and Amargosa Valley, which is 14 to 28 miles south of the site. Beatty and Amargosa Valley are downwind of the site less than 5 percent and about 10 percent of the time, respectively.

<u>Extreme-weather phenomena</u>. This major consideration addresses the historical frequency and intensity of extreme-weather phenomena--such as hurricanes, tornadoes, floods, and winter storms--that could have a significant effect on repository operation or closure. It relates to the

concern in the qualifying condition with meteorological conditions that could lead to unacceptable levels of exposure to persons in unrestricted areas. It is derived from the second potentially adverse condition of the meteorology guideline. This consideration is less important than the first major consideration because, unlike atmospheric transport characteristics, which tend to reflect prevailing meteorological conditions, extreme-weather phenomena are episodic conditions. A summary of the evaluation for each site follows.

Hurricanes are not known to occur in the Davis Canyon site area, and tornadoes are unlikely. The area is not subject to heavy snowfalls, but snowfalls greater than 1 inch occur 10 to 20 days per year. Local flooding or local heavy fog may occur about 8 days per year.

Extreme weather such as local flooding, hurricanes, tornadoes, freezing rain, and heavy fog occur in the area of the Deaf Smith County site about 29-31 days per year. The area also experiences dust storms with winds exceeding 65 mph. There are usually snowstorms less than one day per year.

Extreme-weather conditions occur infrequently at the Hanford site. Tornadoes are rare, and severe winter storms are seldom experienced.

Local flooding, hurricanes, tornadoes, and heavy fog occur in the Richton site area 30 to 70 days a year. Freezing rain, high winds, or snowstorms usually occur less than one day per year.

The frequency of extreme weather at the Yucca Mountain site is among the lowest in the nation. High winds, snowfall, and tornadoes are rare, and the area does not experience severe local flooding. Sandstorms are common, but they would rarely be severe enough to disrupt repository operation.

Summary of comparative evaluation

The Yucca Mountain site is the most favorable under the meteorology guideline. Meteorological data from Yucca Flat suggest that good dispersion conditions are likely to prevail at the site. Prevailing winds would not be likely to preferentially transport radionuclides toward population concentrations. The Yucca Mountain area has a low frequency and magnitude of extreme weather. Meteorological data from the Hanford Site show good dispersion conditions and a low incidence of extreme weather. The favorability of the Hanford site is reduced by the presence of major population centers in the prevailing downwind direction. The Deaf Smith and the Richton sites are both expected to have good dispersion characteristics. Their favorability is reduced in comparison to the Hanford site because they experience more severe weather. Davis Canyon is the least favorable for meteorology. The favorability of this site is reduced by the presence of a population center in the prevailing downwind direction, reduced dispersion conditions, and a greater frequency of severe weather.

7.3.1.1.4 Offsite installations and operations

The qualifying condition for the preclosure guideline on offsite installations and operations is as follows:

> The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and, (2) when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in §960.5-1(a)(1).

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-12), two major considerations influence a site's favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the presence of nearby nuclear installations or operations and (2) the presence of nearby hazardous installations or operations.

Evaluation of sites in terms of the major considerations

Nearby nuclear installations or operations. This major consideration addresses radionuclide releases from atomic-energy defense activities and nuclear installations regulated by the NRC, which could, together with operational releases from the repository, subject the general public to radionuclide exposures above allowable limits. The evaluation accounts for the proximity of nuclear installations and operations to the site and the levels of radionuclide releases that could be expected during accidents and routine operating conditions at these installations. This consideration is derived from the favorable condition and the second potentially adverse condition. It relates directly to the qualifying condition's concern with the potential contribution of other nuclear facilities to radionuclide releases from the repository. This major consideration is assigned greater importance than nearby hazardous installations in this evaluation because of the primary focus in the qualifying condition on compliance with regulations on releases.

In evaluating this consideration, the term "nearby" for offsite installations and operations is defined as the area within 5 miles of the site. The assessment of potential cumulative impacts considers nuclear facilities within 50 miles. A summary of this consideration for each site follows.

At the Davis Canyon site, the only nearby nuclear operations are three uranium mills, which are 36 to 58 miles from the site. The combined radionuclide releases from the uranium mills and a repository at the site would be significantly lower than the specified limits.

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Table 7-12. Guideline-condition findings by major consideration—offsite installations and operations[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: NEARBY NUCLEAR INSTALLATIONS OR OPERATIONS					
Favorable condition 1					
Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.	NP	NP	NP	P	P
Potentially adverse condition 2					
Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: NEARBY HAZARDOUS INSTALLATIONS OR OPERATIONS					
Potentially adverse condition 1					
The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.	NP	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is <u>not</u> present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.
[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

The Deaf Smith site is 48 miles from the Pantex Plant, a major atomic energy defense facility near Amarillo. Releases from this plant are predicted to be only a small fraction of the specified limits and would not significantly contribute to radionuclide levels in the vicinity of the repository. There are no other nuclear facilities in the vicinity.

Commercial nuclear facilities near the Hanford site include one operating nuclear power plant of the Washington Public Power Supply System, commercial site for the disposal of low-level radioactive waste, and a plant that fabricates nuclear fuel. The predicted releases from these facilities are substantially less than the maximum permissible value and would not contribute significantly to radionuclide levels in the vicinity of the repository. DOE-owned nuclear facilities near the repository site include a plutonium-production reactor, the Purex reprocessing plant, and a reactor for testing breeder reactor fuels and components. The postulated worst-case accident at these facilities would result in a radiation exposure at the boundary of the Hanford Site that would be below applicable limits.

The Richton site has no nearby nuclear facilities, nor are there any facilities subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A, within 50 miles of the site.

At the Yucca Mountain site, there are no nearby nuclear facilities that are subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A. Potential sources of radionuclide emissions in the area are a commercial site for low-level-waste disposal about 19 miles west of Yucca Mountain, and the research with spent fuel at the Nevada Research and Development Area, which is adjacent to the east side of Yucca Mountain. The releases resulting from the postulated worst-case accident at these facilities would culminate in total radiation releases at the Nevada Test Site boundary below applicable limits. Most of the radioactive emissions from underground nuclear testing at the Nevada Test Site are contained.

Nearby hazardous installations or operations. This major consideration addresses the possible adverse effects of nearby hazardous operations and installations on repository siting, construction, operation, closure, or decommissioning. Such operations and installations could include chemical plants; fuel production, refining, transportation, and storage facilities; pipelines; major transportation routes used that could carry hazardous materials; air traffic associated with nearby airports; military operations areas; toxic materials handling facilities; and sites for hazardous-waste disposal. These facilities or operations are considered hazardous if they could affect repository operations or worker safety. Potential hazards could include shock waves from explosions, incendiary fragments, and flammable or toxic vapor clouds. This major consideration is derived from the first potentially adverse condition. It relates directly to the concern in the qualifying condition with adverse impacts of nearby hazardous installations and operations on repository operation or closure. A summary of the evaluation for each site follows.

At Davis Canyon, there are no hazardous installations within 5 miles. The site is more than 35 miles from the airports at Blanding and Monticello and more than 18 miles from the San Juan County airport. The nearest State highway is more than 5 miles from the site. Therefore, there are no hazardous installations or operations that are likely to affect a repository at Davis Canyon.

At the Deaf Smith County a 4-inch natural-gas pipeline passes within 3,000 feet of the restricted area, but it does not constitute a hazard to a repository. U.S. Highway 385 passes within 3 miles of the site. Trucks using this highway may carry hazardous cargoes that could affect the repository in a serious transportation accident.

Potentially hazardous installations and operations in the vicinity of the Hanford site include national defense and waste-management facilities. Potentially hazardous facilities include a plutonium-production reactor, a reprocessing plant within 1.8 miles of the site, and a reactor for testing breeder reactor fuels and components within 12 miles of the site. A serious accident at any of these facilities would disrupt repository operations.

The Richton site has several nearby potentially hazardous installations and operations. The Richton Airport is within 3 miles of the site, but the probability of an air crash at the site is extremely low. A portion of the restricted airspace of the DeSoto Military Operations Area is within 5 miles. Future expansion or a more intensive use of the restricted airspace could increase the risk of an airplane crash. A 16-inch underground gas pipeline passes 1 mile from the site, but it does not constitute a credible hazard to a repository. There are two producing oil fields within 3 miles of the site. Explosions or fires at these facilities are unlikely to affect a repository at the site. State Highways 42 and 15 pass within 2 and 3 miles of the site, respectively. These highways could be used for hazardous cargoes. The nearest railroad is more than 12 miles from the Richton site.

The Yucca Mountain site has several nearby hazardous installations and operations, including the underground testing of nuclear devices, an Air Force range, and the Nevada Research and Development Area. Underground testing of nuclear weapons occurs about 10 to 20 times per year at the Nevada Test Site, which is more than 24 miles from Yucca Mountain. Some of this testing might require that underground repository activities be temporarily suspended. The Yucca Mountain site occupies a small portion of the Nellis Air Force Range, which is used for aircraft overflights but not as a target area. The only potential hazard from these overflights is the very remote chance that an airplane carrying ordinance could crash at Yucca Mountain. Research with spent fuel is performed at the Nevada Research and Development Area, which includes a major portion of Yucca Mountain. (The spent fuel is tentatively scheduled for removal in 1986.) However, these research activities are not likely to affect repository operations.

<u>Summary of comparative evaluations</u>

The Davis Canyon and the Richton sites are the most favorable for the guideline on offsite installations and operations. There are no nuclear facilities or other facilities subject to 40 CFR Part 190 or 40 CFR Part 191, Subpart A, located within 50 miles of the Richton site. Potentially hazardous facilities near the site include a major State highway, a gas pipeline, an oil field, an airport, and restricted airspace associated with Camp Shelby. However, these facilities detract less from a site's favorability than a nearby nuclear installation would. At Davis Canyon, the only potential sources of radioactive emissions in the area of the site are three uranium mills. Radionuclide releases from these facilities would not contribute significantly to releases from a repository. There are no nearby hazardous installations or operations that are likely to pose a credible risk to a repository. The Deaf Smith site is slightly less favorable. The only potential source of radioactive emissions is the Pantex plant, but the contributions from this plant are not expected to be significant. Potentially hazardous installations and operations near the site include a major U.S. Highway. There are no nuclear facilities subject to 40 CFR Part 190 or Part 191, Subpart A, located near the Yucca Mountain site. Nonetheless, several potential sources of radioactivity that reduce its favorability are within 50 miles, including nuclear weapons testing and radioactive-waste disposal. The Hanford site is the least favorable for this guideline: there are potentially hazardous national defense facilities or other facilities subject to 40 CFR Part 190 near the Hanford site that could affect repository operations.

7.3.1.2 Preclosure system guideline for radiological safety

The preclosure system guideline for radiological safety requires that any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A. The evidence does not support a finding that any of the sites is not likely to meet this qualifying condition.

The pertinent system elements are (1) the site-specific characteristics that affect radionuclide transport through the surroundings; (2) the engineered components whose function is to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. This guideline is assigned the greatest importance among the preclosure system guidelines because it is directed at protecting both the public and the repository workers from exposures to radiation. To provide a comparative context for understanding the evaluation for this preclosure system guideline in Chapter 6, a brief summary of the evaluation of each of the sites with respect to the pertinent system elements is presented below.

With the exception of meteorological conditions, the Davis Canyon site has favorable characteristics for preclosure radiological safety. From an integrated-system viewpoint, atmospheric dispersion conditions that could be poor at times are not likely to prevent compliance with the radiation protection requirements. However, radioactivity releases from a repository are predicted to be small and are expected to more than compensate for the less than favorable atmospheric dispersion. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose of more than 1.3 millirem during the construction period or more than 1.8 millirem in any year during the operational period. On comparing these values with the regulatory limits (40 CFR Part 191) of 25 millirem per year to the whole body or approximately 140 millirem per year from natural background radiation, it appears that a repository can be located and operated at the Davis Canyon site with insignificant radiological risks to the public.

The Deaf Smith site also has generally favorable characteristics for preclosure radiological safety. A potentially adverse condition is that the dominant wind direction is from the south, and the city of Vega is approximately 8 miles to the north. However, the radioactive releases from the repository are predicted to be very small, and therefore compliance is likely. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose greater than 0.04 millirem during construction or greater than 0.17 millirem in any year from normal operations during the operational period. Comparing these values with the limits of 40 CFR Part 191 (25 millirem per year to the whole body) or with approximately 95 millirem per year from natural background, it appears that a repository at the Deaf Smith site would pose insignificant radiological risks to the public.

The Hanford site has favorable characteristics pertinent to preclosure radiological safety. The meteorological conditions in the area show good atmospheric dispersion and infrequent occurrences of extreme weather. Moreover, there are no permanent residents at the site. Because of the very small radionuclide releases from the repository, the low population density in the surrounding area and the distance from the repository to highly populated areas, routine repository operations would not be expected to exceed the regulatory limits for the exposure of the general public to radiation. The individual radiation doses from other operations in the vicinity of the Hanford Site are greater than that projected for the repository. These doses are monitored and are within applicable Federal standards.

At the Richton Dome, the site characteristics that are pertinent to preclosure radiological safety are generally favorable except for meteorological conditions, which could be poor at times, with occasional stagnant conditions. From an integrated-system viewpoint, these conditions are not likely to prevent compliance with the radiation-protection requirements. Radioactive releases from a repository are predicted to be very small, which would more than compensate for the less-than-favorable atmospheric dispersion conditions. Modeling results indicate that no member of the public is likely to receive an annual whole-body dose greater than 0.41 millirem during the construction period. A comparison with the limits of 40 CFR Part 191 (25 millirem per year to the whole body or approximately 10 millirem per year from natural background radiation), it appears that a repository at the Richton site can be operated without significant radiological risks to the public.

At Yucca Mountain the meteorological characteristics favor the ability of the site to limit exposure to radiation among workers and the public; the distribution of people who live outside the area would also restrict exposures. Estimates of both the extreme worst-case accidental radiological exposures to the general public and the exposures due to normal operation are below the limits specified in 10 CFR Part 20 (1984), 10 CFR Part 60 (1983), and 40 CFR 191, Subpart A (1985). Estimated releases under normal repository operation (Section 6.4.1) produce radionuclide concentrations that are well below the maximum permissible concentrations.

The evidence does not support a finding that any of the sites is not likely to meet the qualifying condition for preclosure radiological safety.

7.3.2 ENVIRONMENT, SOCIOECONOMICS, AND TRANSPORTATION

7.3.2.1 Technical guidelines

Three technical guidelines are associated with the preclosure system guideline on environmental quality, socioeconomics, and transportation. Their objective is to ensure that the public and the environment are protected from the effects of repository construction, operation, closure, and decommissioning.

7.3.2.1.1 Environmental quality

The qualifying condition for the environmental quality guideline is as follows:

> The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in §960.5-1(a)(2) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-13), four major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. These major considerations are (1) the ability to meet applicable environmental requirements, (2) the ability to mitigate environmental impacts, (3) the absence of protected Federal resource areas as well as threatened and endangered plant and animal species, and (4) the absence of protected State or regional resource areas, Native American resources, and cultural sites. As a group, major considerations 1 and 2 are more important than major considerations 3 and 4, but the factors within each group are considered to be of equal importance.

Evaluation of sites in terms of the to major considerations

Ability to meet applicable environmental requirements. This major consideration addresses the procedural and substantive requirements of environmental regulations with which the repository must comply. It addresses

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Table 7-13. Guideline-condition findings by major consideration--environmental quality[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: ABILITY TO MEET APPLICABLE ENVIRONMENTAL REQUIREMENTS					
Favorable condition 1					
Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.	NP	NP	P	NP	P
Potentially adverse condition 1					
Projected major conflict with applicable Federal, State, or local environmental requirements.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: ABILITY TO MITIGATE ENVIRONMENTAL IMPACTS					
Favorable condition 2					
Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.	NP	NP	P	NP	P
Potentially adverse condition 2					
Projected significant adverse environmental impacts that cannot be avoided or mitigated.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 3: PROTECTED FEDERAL RESOURCE AREAS					
Potentially adverse condition 3					
Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.	P	NP	NP	P	NP
Potentially adverse condition 6					
Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.	NP	NP	NP	NP	NP

Table 7-13. Guideline-condition findings by major consideration—environmental quality[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: PROTECTED STATE OR REGIONAL RESOURCE AREAS, NATIVE AMERICAN RESOURCES, CULTURAL SITES					
Potentially adverse condition 4					
Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.	P	NP	NP	NP	NP
Potentially adverse condition 5					
Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.	NP	NP	NP	NP	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is <u>not</u> present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

applicable site-specific regulations at the Federal, State, and local levels. A site's standing against this consideration is determined by evaluating the degree to which repository activities will comply with requirements as well as the ability to do so within specific time constraints. This consideration relates directly to the qualifying condition and the first favorable and potentially adverse conditions, which address the ability to comply with environmental requirements within time constraints. Because compliance with environmental requirements is a measure of the ability to protect the environment at a site, this consideration is a direct indicator of a site's ability to meet the qualifying condition for environmental quality. Table 6-2 and Table 6-3 in each EA (Table 6-9 and Table 6-10 in the Yucca Mountain EA) summarize actions that are planned at the sites to ensure they comply with applicable requirements and review their ability to meet each requirement. A summary of the evaluation for each site follows.

The Davis Canyon site is expected to meet all potentially applicable environmental requirements. However, it may not be possible to do so within time constraints because of uncertainties about the time required to obtain certain permits, such as those required under the Utah Air Conservation Act.

The Deaf Smith site is expected to meet all potentially applicable environmental requirements. However, it may not be possible to do so within time constraints because of uncertainties regarding the time required to comply with requirements like the Texas Drilled and Mined Shaft Act.

The Hanford site is an area that has been dedicated to nuclear activities since 1943. The environmental requirements are known for the area, and it is expected that the site will be able to meet the potentially applicable environmental requirements within time constraints.

The Richton and Yucca Mountain sites are expected to meet all potentially applicable environmental requirements, but the Richton site may not do so within time constraints because of uncertainties regarding the time to obtain certain permits.

Ability to mitigate environmental impacts. This consideration evaluates the significance of the environmental impacts of the repository and accounts for the degree to which impacts can be mitigated. It also considers features of the mitigation measures, such as their time requirements and technological feasibility, and the social, economic, or environmental factors that affect their applicability to a particular site. This consideration relates directly to the qualifying condition and the second favorable and potentially adverse conditions, which address the ability to mitigate impacts at each site. Because of its direct relevance to the qualifying condition, the environmental-impact consideration is a direct indicator of a site's ability to meet the qualifying condition for the environmental-quality guideline. A summary of the evaluation for this consideration for each site follows.

It is projected that all potentially significant impacts at the Davis Canyon site can be avoided or mitigated to an acceptable level. However, extensive mitigation measures would be required because of the close proximity of Canyonlands National Park. Although it is projected that all applicable environmental impact standards can be met, some impacts cannot be mitigated to insignificant levels. For example, construction and operation noise will be audible within Canyonlands National Park, and access corridors and facilities will be visible from the Park. Night-sky glow from project lighting may also be visible within the Park.

It is projected that all potentially significant impacts at the Davis Canyon site can be avoided or mitigated to an acceptable level and all applicable environmental standards can be met. However, extensive mitigation measures would be required because of the close proximity of Canyonlands National Park. Furthermore, some impacts cannot be mitigated to insignificant levels. For example, construction and operation noise will be audible within the Canyonlands National Park, and access corridors and facilities will be visible from the Park. Night skyglow from repository lights may also be visible within the Park.

At the Deaf Smith site, it is projected that all potentially significant impacts can be avoided or mitigated to an acceptable level and that all applicable environmental standards can be met. However, some impacts cannot be mitigated to insignificant levels. For example, about 5,760 acres of farmland will be permanently removed from production.

At the Hanford site, all potentially significant impacts can be avoided or mitigated to insignificant levels. No noise or air-quality impacts are expected outside the boundary of the larger Hanford Site, and no impacts are projected for the Columbia River. Potential impacts associated with offsite developments will be mitigated through siting and engineering measures.

At the Richton site, it is projected that all potentially significant impacts can be avoided or mitigated to an acceptable level, and that all applicable environmental standards can be met. However, some impacts cannot be mitigated to insignificant levels. The repository will be visible, and noise will be audible in offsite areas.

It is projected that all potentially significant impacts at the Yucca Mountain site can be avoided or mitigated to insignificant levels. Air-quality impacts at the controlled-area boundary will be maintained within the limits specified in applicable regulations. Releases of radioactivity from naturally occurring material will increase during the excavation of the underground facility, but they are not expected to be significant.

Protected Federal resource areas. This consideration relates directly to the third and sixth potentially adverse conditions. It addresses the following Federal lands that are identified in these conditions: the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, and National Forest Land, as well as designated critical habitats for threatened or endangered species. The evaluation of sites for this consideration is based on their proximity to, and the degree of projected impacts on, the listed areas, except for critical habitats. Critical habitats are considered on the basis of whether they could be compromised by the repository. Because this consideration addresses the protection of environmental quality in terms of a subset of environmental conditions (i.e., specifically identified resource areas), it is relatively less important in the overall evaluation of sites than the first two considerations. A summary of the evaluation for each site follows.

The repository operations area at the Davis Canyon site is within 1 mile of the eastern boundary of the Canyonlands National Park and is considered to be proximate to the Park. Impacts on the park include increased suspended particulate and nitrogen oxides, increased noise levels, visibility of repository facilities, temporarily disrupted access, and night skyglow. There are no known or designated critical habitats for threatened or endangered species that could be compromised by the repository or its support facilities, although there are crucial riparian habitats.

The Federal resource area nearest to the Deaf Smith site, the Buffalo Lake National Wildlife Refuge, is 22 miles from the site. No significant adverse impacts are projected for this resource. There are no critical habitats for threatened or endangered species within the site or site vicinity that could be compromised by the repository or its support facilities.

The Hanford site is on Federal land not designated for protection. The site is 4 miles from the Saddle Mountains Wildlife Refuge (a multipurpose area of the Hanford Site) and 16 miles from the McNary National Wildlife Refuge. No significant adverse impacts are projected for these wildlife refuges. No federally recognized threatened or endangered species are known to inhabit the Hanford site, though several species (e.g., the bald eagle and the peregrine falcon) have been sighted within the site. Three species of birds that are candidates for designation as threatened or endangered nest within or near the site.

The Richton site is 2.5 miles from the DeSoto National Forest, but no significant adverse impacts are projected for the forest. There are no known or designated critical habitats for threatened or endangered species that could be compromised by the repository or its support facilities.

At the Yucca Mountain site, the northern part of the controlled area is 5 miles from the Timber Mountain Caldera National Natural Landmark, which lies within the Nellis Air Force Range and the Nevada Test Site. The Toiyabe National Forest is about 50 miles from the site, and the Death Valley National Monument is 20 to 25 miles from the site. The rail line to the site will pass within several miles of the Desert National Wildlife Range, parts of which are suitable for inclusion in the Wilderness Preservation System. There are no critical habitats at the Yucca Mountain site. Ash Meadows, which contains several protected species, is about 25 miles away. No significant adverse impacts are projected for any designated Federal lands or protected species.

<u>Protected State or regional resource areas, Native American resources, and cultural sites</u>. This consideration relates directly to the fourth and fifth potentially adverse considerations. The fourth potentially adverse condition identifies three significant State or regionally protected resource areas: State parks, wildlife areas, and historical areas. The fifth potentially adverse condition requires an evaluation of significant Native American resources, such as religious sites, and other sites of unique cultural interest. The evaluation addresses the combined effects of a site's proximity to resource areas and the projected level of impact on those areas. Because this consideration addresses the protection of environmental quality in terms of a subset of environmental conditions (i.e., specific resource areas), it is equal in importance to the third consideration but less important than the first two considerations. A summary of the evaluation for each site follows.

The Newspaper Rock State Historical Monument is near Utah State Highway 211, 17 miles from the Davis Canyon site. The petroglyph panel at Newspaper Rock is a significant cultural resource and is listed on the National Register of Historic Places. The increased traffic flow past the Monument that would be associated with a repository at Davis Canyon will disrupt some visitation and overnight camping at the Monument. The nearest State park is the Dead Horse State Park, which is 30 miles away. The nearest significant Native American resource or site of unique cultural interest is the Salt Creek Archaeological District, which lies along the eastern edge of the Canyonlands National Park. Impacts of the repository and support facilities on these resources are not expected to be significant.

The State protected resource nearest to the Deaf Smith site is the Palo Duro Canyon State Park, located 44 miles away. Since no significant State, regional, or Native American resources are known to be present in the area of the site, no significant adverse impacts are expected.

A repository at the Hanford site would not affect any protected resource area. There are no known significant State, regional, or Native American resources within or adjacent to the site. There are significant Native American resources along the shorelands of the Columbia River, 4 miles from the site, but no significant adverse impacts are projected for these resources.

The nearest State or regionally protected resource to the Richton site is the Paul E. Johnson State Park, which is 20 miles away. The park is not expected to experience any significant adverse impacts. There are no significant Native American resources or cultural sites recorded at the Richton site, and the potential for discovering such resources is considered low.

The Yucca Mountain site is not located near any State or regionally protected resource area. The rail corridor that would be constructed to the site is not projected to adversely affect any resource areas, although it will pass within 0.9 mile of the F. R. Lamb State Park. Most of the Yucca Mountain site has been surveyed for cultural artifacts. Limited investigations have identified 178 prehistoric and 6 historic sites, many of which consist of scattered debris. No major impacts are projected for any significant Native American resource or unique cultural site.

Summary of comparative evaluation

The Hanford and the Yucca Mountain sites are most favorable under the environmental-quality guideline. Both sites are expected to meet all major environmental requirements within time constraints. Adverse environmental impacts at both sites can be avoided or mitigated to insignificant levels. Since these sites are not near any protected Federal, State, or regionally protected resource, or near any significant Native American resource or site of unique cultural interest, the development of a repository at either of these sites is not projected to have significant impacts on any of these resources.

The Deaf Smith site can comply with all potentially applicable environmental requirements, but may not be able to do so within time constraints. Similarly, it is projected that adverse impacts at the site can be limited to acceptable, but not insignificant, levels. The Deaf Smith site is favorable with regard to the third (protected Federal resource areas) and the fourth (protected State or Native American resources) major considerations because the site is not near any of the relevant resource areas and would not be expected to adversely impact such areas.

The Richton site is also expected to meet all applicable environmental requirements, although it may not be able to do so within time constraints. All adverse impacts at the site can be avoided or mitigated, but not to insignificant levels. The Richton site is less favorable than the Hanford, Yucca Mountain, and Deaf Smith sites with respect to protected Federal resource areas because of its proximity to the DeSoto National Forest. The Richton site is favorable with regard to the fourth consideration (protected State or Native American resources) because a repository at this site is not projected to cause adverse impacts on any State or regionally protected resource area, significant Native American resource, or site of unique cultural interest.

The Davis Canyon site is the least favorable for the environmental-quality guideline. It is projected that all potentially applicable environmental requirements can be met, but it may not be possible to do so within time constraints. It is also projected that adverse impacts can be mitigated to acceptable but not insignificant levels. The favorability of the Davis Canyon site is further reduced by its proximity to, and potential impacts on, the Canyonlands National Park and the Newspaper Rock State Historical Monument.

7.3.2.1.2 Socioeconomic impacts

The qualifying condition for the socioeconomics guideline is as follows:

> The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian Tribes; and (2) the requirements specified in 960.5-1(a)(2) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-14), six major considerations are identified that influence the favorability of the sites with respect to the qualifying condition. These major considerations are (1) potential impacts on community services and housing, (2) potential impacts on direct and indirect employment and business sales, (3) potential impacts on primary sectors of the economy, (4) potential impacts on the revenues and expenditures of public agencies, (5) the need to purchase or acquire water rights that could affect development in the area, and (6) potential social impacts. No order of importance is assigned to these six considerations. Each consideration is, in turn, influenced by a number of more-specific conditions or contributing factors, which are discussed below.

Table 7-14. Guideline-condition findings by major consideration--socioeconomics[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL IMPACTS TO COMMUNITY SERVICES AND HOUSING					
Favorable condition 1					
Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	NP	P	P	P	P
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL IMPACTS ON DIRECT AND INDIRECT EMPLOYMENT AND BUSINESS SALES					
Favorable condition 2					
Availability of an adequate labor force in the affected area.	NP	NP	NP	NP	NP
Favorable condition 3					
Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	P	P	P	P	P
Potentially adverse condition 2					
Lack of an adequate labor force in the affected area.	P	P	P	P	P
MAJOR CONSIDERATION 3: POTENTIAL IMPACTS TO PRIMARY SECTORS OF THE ECONOMY					
Favorable condition 4					
No projected substantial disruption of primary sectors of the economy of the affected area.	P	P	P	P	P
Potentially adverse condition 4					
Potential for major disruptions of primary sectors of the economy of the affected area.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 4: POTENTIAL IMPACTS TO THE REVENUES AND EXPENDITURES OF PUBLIC AGENCIES					
Favorable condition 3					
Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.	P	P	P	P	P

Table 7-14. Guideline-condition findings by major consideration--socioeconomics[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: POTENTIAL IMPACTS TO THE REVENUES AND EXPENDITURES OF PUBLIC AGENCIES (Continued)					
Favorable condition 3 (continued)					
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.	P	NP	NP	NP	NP
MAJOR CONSIDERATION 5: THE NEED TO PURCHASE OR ACQUIRE WATER RIGHTS THAT COULD EFFECT DEVELOPMENT IN THE AREA					
Potentially adverse condition 3					
Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 6: POTENTIAL SOCIAL IMPACTS					
Favorable condition 1					
Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.	NP	P	P	P	P
Potentially adverse condition 1					
Potential for significant repository-related impacts on community services, housing, supply and demand, and the finances of state and local government agencies in the affected area.	P	NP	NP	NP	NP

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is <u>not</u> present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

Evaluation of the sites in terms of the major considerations

Potential impacts on community services and housing. This consideration relates to the requirement in the qualifying condition that impacts on community services or housing in affected areas and communities can be mitigated or compensated for. This consideration is derived from the first favorable condition and the first potentially adverse condition. The first favorable condition focuses on the ability of the affected area to absorb repository-related population growth without disrupting community services and the supply and demand for housing. The potentially adverse condition addresses impacts on community services and housing in communities near a potential site. Impacts on community services and housing depend on five contributing factors: population composition and density, the distribution of in-migrants, current capacity and trends in the use of community services and infrastructure, housing supply and demand, and the community's ability to accommodate growth. A site's favorability improves as the combination of these contributing factors leads to fewer impacts on community services and housing. A summary of the evaluation for each site follows.

A repository at the Davis Canyon site is likely to result in substantial impacts on community services and housing in the affected area. The projected net change in the population of Grand and San Juan Counties is expected to be approximately 20 percent above the baseline population during the peak of in-migration. This level of population increase may cause a significant disruption in housing and community services. The number of housing units needed by repository-related households could reach 1,600 units. Fewer than half this number of units are currently available in the study area. The communities of Moab, Monticello, and Blanding are projected to have peak-year cumulative growth rates of 31, 50, and 24 percent, respectively. Although this level of growth would occur over a 6-year period, it would cause significant impacts.

The development of a repository at the Deaf Smith site is not expected to result in major impacts to community services or housing. Most project in-migrants are expected to locate in Amarillo, about 40 miles from the site. Amarillo is a large urban center that has a sufficient community infrastructure to accommodate repository workers and their families. Vega, which is the closest community to the site, is projected to experience a peak-year cumulative growth of 8 percent. Since this growth would occur over a 6-year period, it is not considered to have potential for significantly disrupting the community. However, in-migration is expected to cause some minimal increase in the demand for community services (e.g., housing, schools, police protection, medical services, water supply, and recreation) in the affected area.

The Tri-Cities (Richland, Kenewick, and Pasco) have historically received most of the in-migrating work force associated with large projects at the Hanford Site. If the most likely estimate of 1,700 in-migrants for the repository is used, annual growth rates during the peak year would be less than 4 percent for all communities. These annual growth rates are low in comparison with previous levels of growth in the area. There is also a large and underused infrastructure, particularly excess housing, in the Tri-Cities area. This suggests that the development of a repository at Hanford represents an opportunity for the area to more fully use its resources. Therefore, community-services and housing impacts are projected to be favorable.

For the Richton site, the capacity of housing in counties receiving in-migrants is expected to be adequate. Because the availability of community services generally parallels the availability of housing, these services are also expected to be adequate in the affected area. At a community level, the town of Richton is projected to experience a peak-year cumulative growth of 37 percent. This growth would occur over a 4-year period. Although the average annual growth rate is higher than the 6-percent growth rate projected for Richton's baseline population, significant disruption is not expected. Nonetheless, the in-migrating population is projected to cause moderate service impacts in the study area, including the need for some additional housing, teachers, police officers, physicians, hospital beds, and water and sewage facilities.

For the Yucca Mountain site, over 80 percent of the in-migrants are expected to settle in the Los Vegas area, where the infrastructure is sufficient to accommodate them. In the rural communities closer to the site, the maximum 1-year growth rates, which are projected from the historical settlement patterns of workers at the Nevada Test Site, will be less than 5 percent for all communities near the site except Pahrump (5 percent) and Indian Springs (13.2 percent). Although demands for services and housing in communities could increase in proportion to these peak 1-year growth rates, the potential impacts would be largely confined to the service providers that are best equipped for dealing with growth. Generally, services in the unincorporated communities near the site (i.e., Indian Springs, Pahrump, Beatty, and Amargosa Valley) are provided not by town governments but by county-wide agencies that have broad tax bases, planning capabilities, and experience in responding to population growth rates within the range of those projected for the repository. With only a few exceptions, water in the unincorporated communities near the repository site is supplied by private wells, and waste water is disposed of in private septic tanks and leach fields. In addition, housing in rural southern Nevada is provided almost entirely by the private sector.

<u>Potential impacts on direct and indirect employment and business sales</u>. This major consideration is derived from the second and the third favorable conditions and the second potentially adverse condition. Two factors contribute to the potential for increased direct and indirect employment and business sales: repository-related needs for labor and expected local hires, and repository-related local purchases of materials. This major consideration is related to the qualifying condition in that increased local employment and business sales enhance the ability of affected areas and communities to absorb repository-related growth by increasing business and tax revenues. A site's favorability increases with repository-related economic growth. A summary of the evaluation for each site follows.

At the Davis Canyon site, a repository is expected to generate over 2,000 direct and indirect jobs at its peak, of which about 400 are expected to be filled by local residents. The repository is also expected to generate about $5.4 million per year in local purchases during the construction phase.

At the Deaf Smith site, local residents are expected to fill 1,380 of the total number of jobs at the peak of repository development. Direct local purchases of about $11.3 million per year are projected during repository construction. An additional $5.7 million per year is expected to be spent as a result of indirect effects caused by material purchases.

At the Hanford site, total employment could increase by more than 2,400 at the peak of repository development. A substantial number of these jobs will be filled locally. In addition, substantial spending through wages and on purchases of materials from local suppliers is expected.

At the Richton site, the repository is expected to generate about 1,300 jobs for local residents at the peak of its development. In addition, about $5.3 million in direct local material purchases will be made during repository construction.

For the Yucca Mountain site, up to 4,800 jobs could be created during peak repository development. Many of these jobs are expected to be filled by current residents of the area. The increases in area income from wages for repository construction and operation could reach $110 million in 1998.

Potential impacts on primary sectors of the economy. The third major consideration is derived from the fourth favorable condition and fourth potentially adverse condition. The contributing factors are major sectors of the economy, employment distribution and trends by economic sector, and the compatibility of a repository with the area's economic base. The smaller any projected disruption, the greater the site's favorability. A summary of the evaluation for each site follows.

Primary sectors of the Davis Canyon study area are retail trade and services (31 percent of employment), government (24 percent of employment), and mining (14 percent of employment). Since unemployment in mining has increased significantly in the last 6 years, a repository may have a positive effect on this sector. The extent of this positive effect is unknown, because significant numbers of miners have left the area since 1983. The demands on local government created by new growth should create jobs in the government sector. In retail trade and services, tourism represents approximately 475 man-years of employment for San Juan and Grand Counties or about 24 percent of the jobs in these sectors. Because the Canyonlands National Park is near the repository, some tourists may choose to avoid the park, and some jobs related to tourism could be lost. The total number of jobs directly associated with purchases made by tourists with Canyonlands as their primary destination is approximately 76 man-years of employment. The local retail-and-service jobs directly related to local purchases associated with the repository will average 240 man-years of employment during construction and 230 man-years during operation. Therefore, while some tourism-related jobs in the retail and service sectors may be lost, other jobs are expected to be created.

The primary sectors of the Deaf Smith study area are government (18 percent), retail trade (15 percent), services (14 percent), agriculture (10 percent), and manufacturing (10 percent). It is expected that the repository will increase the need for products and services provided by the retail trade, government, and service sectors. No substantial loss of employment due to the repository is expected for the agricultural or manufacturing sectors because most of their markets are outside the region of the site. However, the sales of health foods and bottled water could decline. In addition, projected impacts on the agricultural sector include a loss of more than $1.6 million in crop and livestock revenues at the peak of construction (about 0.12 percent of the expected crop and livestock revenues in the region in 1997); a loss of $1.7 million in crop and livestock revenues at the peak of operation; a loss of $2.5 million and $3.0 million in agricultural business during the peak of repository construction and operation, respectively; and a loss of 0.61 percent of the productive land in Deaf Smith County.

In the affected area of the Hanford site, the potential for major disruptions of primary sectors of the economy is very small. The primary sectors of employment are the Washington Public Power Supply System and its contractors, the DOE and its contractors, and agriculture. A repository at the Hanford site would probably stabilize economic conditions and employment in the area.

In the affected area of the Richton site, the primary economic sectors are manufacturing (21 percent), government (25 percent), and retail trade (22 percent). The repository is not expected to affect markets for manufactured goods. Employment in the trade and government sectors is likely to increase because of increases in wages, local purchases, business sales, and demands for services.

The primary sectors of the economy in southern Nevada are mining and tourism. A repository at Yucca Mountain is expected to increase the number of mining jobs in Nye County. In regard to tourism, even though repository-related increases in population may have a small positive effect, only potential negative impacts have been investigated to date. Preliminary results of an ongoing evaluation are inconclusive. Studies of the effects of well-publicized accidents have yielded no evidence of long-term effects on tourism.

Potential impacts on public agency revenues and expenditures. This consideration is derived from the third favorable condition and the first potentially adverse condition, which addresses the potential for increased revenues, and the net fiscal balances of State and local government agencies, respectively. This consideration relates to the qualifying condition in that the DOE must be able to mitigate adverse economic impacts, including impacts on the finances of State or local governments. Impacts on the revenues and expenditures of public agencies depend on three contributing factors: the sources of, and trends in, the expenditures and revenues of local government; the additional needs for community services induced by the repository project; and economic growth in the area and resulting increases in tax revenues. A site's favorability increases as the repository more positively affects State and local finances and decreases as more mitigation of fiscal impacts is required. A summary of the evaluation for each site follows.

At the Davis Canyon site, a repository will increase the revenues collected through property taxes, sales taxes, and user fees. These increases in revenues, however, may not offset increases in outlays for community services and infrastructure needs.

At the Deaf Smith site, the repository will also increase the revenues collected in property taxes, sales taxes, and user fees. These increases in revenues are expected to offset the projected minimal impacts on community services.

At the Hanford site, the State or local governments will not experience significant adverse fiscal impacts. There are virtually no projected impacts on community services, and there are some economic benefits that will result in additional tax revenues.

The potential impact on the revenues and expenditures of public agencies affected by the Richton site is similar to that at the Deaf Smith site. Revenues from property taxes, sales taxes, and user fees are likely to increase. These revenue increases are expected to offset increases in expenditures due to changes in service requirements.

At the Yucca Mountain site, significant repository-induced expenditures are expected to result in increased State and local tax revenues, which may be offset by additional outlays in the study area.

Need to purchase or acquire water rights that could affect development in the area. This major consideration is derived from the third potentially adverse condition (see Table 7-14). The need to acquire water rights depends on two contributing factors: project-related water requirements and current water rights, use, and capacity. Specifically, the greater the competition for water at the site and the more the DOE's acquisition of water rights could affect development in the area, the lower the site's favorability. A summary of the evaluation for each site follows.

At the Davis Canyon site there is a variety of potential water sources. A likely source of water is the San Juan County Water Conservatory District, which has jurisdiction over the site. The Conservatory District has indicated that it would enter into an agreement for the annual sale or lease of up to 2,800 acre-feet of water from the Colorado River or one of its tributaries during construction and up to 500 acre-feet during the operation of the repository. Because the San Juan Planning Council expects that two new reservoirs that are being built in the Blanding and Monticello area will supply enough water for future needs and because the Council is willing to sell or lease part of its own appropriation, development in the area should not be affected.

The Ogallala aquifer, the major source of water for municipal use and irrigation in the Texas Panhandle and in the area of the Deaf Smith site, is being depleted. The Texas Water Commission predicts that only part of the projected water requirements for irrigated agriculture in 1990 will be met under a high-demand scenario. Although a repository at the Deaf Smith site will require relatively little water to operate in comparison with other industrial users in Texas and less than one-fourth of one percent of projected water supply in the County throughout the life of the repository, the water requirements of the repository will further deplete the aquifer and may compete with other users, especially agricultural users. Municipal and industrial water requirements are expected to be met because these users are able to pay the higher prices associated with more a limited supply.

The Federal Government already owns the water rights that are needed for a repository at the Hanford site. Water will be supplied from the Columbia River by an existing pump station. No significant impacts on municipal water systems in the study area are expected because there is excess capacity in the Tri-Cities area, where most in-migrants would live.

At the Richton site, the DOE will not need to acquire water rights because ground water is expected to be available at the site. In addition, no planned developments in the study area have been identified that would be adversely affected by the water use projected for the repository.

It is projected that sufficient water for a repository at Yucca Mountain can be obtained from new or existing wells at the Nevada Test Site, for which the DOE has existing water rights. For local water systems, secondary impacts due to the increased demand associated with population increases are expected to be minimal, although some communities may require mitigation assistance to expand their water systems to meet the needs of new in-migrants. There are no major developments or population centers that will compete with the repository for ground water. The Las Vegas Valley is projected to have water-supply problems by the year 2020 with or without the population increases resulting from the development of the repository.

Potential social impacts. This major consideration relates directly to the requirement in the qualifying condition that significant social impacts on communities and surrounding areas can be offset by reasonable mitigation or compensation. It also relates to the first favorable and potentially adverse conditions, which address the quality of life by focusing on impacts to community services and the finances of State and local government agencies. Three factors contribute to the potential for social impacts: the quality of life and existing social problems in the affected communities, the size of the in-migrating population in comparison with the existing population, and the compatibility of the in-migrating population with the lifestyles and characteristics of the current residents. The more compatible the in-migrating population with the current population and the fewer the disruptions that it causes, the greater the site's favorability. A summary of the evaluation for each site follows.

At the Davis Canyon site, it is estimated that Moab and Blanding will experience an increase of 31 and 24 percent, respectively, in population during the first 6 years of the repository. Monticello is expected to grow by about 50 percent during the same period. These increases would be dramatic and could lead to conflicts between long-time residents and newcomers over leadership positions. Rapid growth could also contribute to increases in alcohol and drug abuse, crime, and family conflict.

At the Deaf Smith site, Vega is expected to receive an 8-percent increase above the baseline population. On the basis of this population increase, Vega could experience some social changes. The lifestyles of construction workers may not be compatible with long-time residents, though most workers are expected to live in Amarillo or Hereford. Major conflicts over leadership positions between long-term residents and newcomers are not expected.

At the Hanford site, a repository will make a small but positive contribution to the recovery of the area from the decline of the early 1980s. The effect of any impacts on social conditions is likely to be positive. Since expected in-migrating work force is small in comparison with the projected baseline population, serious social disruptions are unlikely. The Yakima Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Tribe are formally designated as affected

Indian Tribes under the Act. A repository at Hanford is not expected to cause significant social impacts on these Indian Tribes.

At the Richton site, the town of Richton is expected to receive 483 repository-related in-migrants, a 37-percent change over baseline projections for the peak year of construction. This repository-related growth for Richton is significant and will probably cause social changes and conflicts over leadership positions in the community.

For the Yucca Mountain site, most of the in-migrating population is projected to be absorbed in Clark County. Since the size of the in-migrating population is small in comparison with the projected baseline population, and the existing social structure in urban Clark County is highly diverse, the growth-related effects on social structure are not expected to be significant. In contrast, Nye County is a rural area where experience with large energy-development projects indicates that growth-related social disruptions could occur. However, preliminary assessments suggest that in-migrating construction workers would be assimilated within the existing social structure. Historically, communities in Nye County have had a large population of miners, and mining continues to be important in the area. Therefore, because of the diversity of existing cultural environments within Nye and Clark Counties, in-migrating workers would be able to select a compatible cultural environment and are likely to be readily assimilated into the community.

Summary of comparative evaluations

The Hanford site is the most favorable for all six major considerations. The Tri-Cities has a large and under-used infrastructure, and the area would benefit from repository-related employment and increases in business sales. The economy of the affected area is largely based on nuclear activities, although there is also substantial agriculture. No significant adverse fiscal or social impacts are expected, and the DOE owns all necessary water rights.

At the Yucca Mountain site, most of the in-migrants are expected to settle in the area of Las Vegas, which has a sufficient infrastructure to accommodate them. Services in the unincorporated communities nearer the site are generally provided by county-wide organizations that are well equipped to deal with growth. Both Nye and Clark Counties are expected to benefit from increased employment and business sales. Employment in the mining industry in Nye County is expected to increase substantially. The tourist industry is not expected to be negatively affected. Public revenues will probably increase, and social impacts are expected to be small. Sufficient water for the repository can be obtained from wells at the Nevada Test Site, and secondary impacts should be minimal.

At the Deaf Smith site, population growth may cause minimal adverse impacts on community services. Vega could also experience social changes because the lifestyles of newcomers and long-time residents may be incompatible. In addition, a repository is expected to cause minor disruption to the agricultural industry in the affected area. Some water may also be diverted from other uses because the DOE will need to acquire water rights in a region where the major source of water is being depleted. The area is expected to benefit from increased employment, business sales, and tax revenues.

At the Richton site, moderate impacts on community services are projected because of the population growth associated with a repository. Local purchases and job opportunities will increase, but adverse social impacts could occur, especially in the town of Richton. Primary sectors of the economy are not expected to be disrupted, and public revenues should increase. There is no need for the DOE to purchase or acquire water rights.

A repository at the Davis Canyon site is expected to induce major adverse impacts on community services and housing; these impacts will occur in San Juan County and in three small communities near the Davis Canyon site. In addition, a significant population growth may cause substantial social impacts. Although a small number of jobs related to tourism in the retail and service sectors may also be lost, net local employment, business sales, and tax revenues should increase. Water rights are likely to be obtained from the San Juan Planning Council without affecting present or future development.

7.3.2.1.3 Transportation

The qualifying condition for the transportation guideline is as follows:

> The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in 960.5-2-5(d)(2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of Section 960.5-1(a)(2) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-15), four major considerations are identified that influence the favorability of sites with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) transportation safety, (2) potential for environmental disruption, (3) the cost of transportation infrastructure, and (4) the cost of transportation hardware and operations. Each of the major considerations is, in turn, influenced by several contributing factors, which are discussed below.

Evaluation of the sites with respect to major considerations

Transportation safety. Transportation to the repository will present a potential hazard, albeit small, to people living along the routes traveled. The hazards are both radiological (i.e., due to the radiological nature of the cargo) and nonradiological (i.e., due to the movement of the transport vehicle and not related to the character of the cargo). The guidelines emphasize that

Table 7-15. Guideline-condition findings by major consideration--transportation[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: THE SAFETY OF TRANSPORTING SPENT FUEL AND HIGH-LEVEL WASTE TO THE REPOSITORY					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparably siting options.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P
Favorable condition 2	NP	P	P	NP	P
Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.					
Favorable condition 4	NP	NP	NP	NP	P
Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.					
Favorable condition 5	NP	NP	NP	P	NP
Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.					
Favorable condition 8	P	P	P	P	P
Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.					
Favorable condition 9	P	P	P	P	P
A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.					

Table 7-15. Guideline-condition findings by major consideration—transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: THE SAFETY OF TRANSPORTING SPENT FUEL AND HIGH-LEVEL WASTE TO THE REPOSITORY (Continued)					
Potentially adverse condition 2	P	NP	NP	NP	NP
Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.					
Potentially adverse condition 3	P	NP	NP	NP	NP
Existing local highways and railroads that could require significant re-construction or upgrading to provide adequate routes to the regional and national transportation system.					
Potentially adverse condition 4	P	NP	NP	NP	P
Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.					
MAJOR CONSIDERATION 2: THE AMOUNT AND NATURE OF THE ENVIRONMENTAL DISRUPTION CAUSED BY DEVELOPING THE TRANSPORTATION NETWORK AND ACCESS ROAD (INFRASTRUCTURE) AROUND AND TO THE SITE					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	NP	NP	P	NP	NP
(iii) Cuts, fills, tunnels, or bridges are not required.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P
Favorable condition 2	NP	NP	P	NP	P
Proximity to local highways and railroads that provide access to regional highways and railroads, and are adequate to serve the repository without significant upgrading or reconstruction.					

7 0 1 6 8 0 0 5 4 3

Table 7-15. Guideline-condition findings by major consideration—transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 2: THE AMOUNT AND NATURE OF THE ENVIRONMENTAL DISRUPTION CAUSED BY DEVELOPING THE TRANSPORTATION NETWORK AND ACCESS ROAD (INFRASTRUCTURE) AROUND AND TO THE SITE (Continued)					
Favorable condition 3	NP	P	P	P	P
Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.					
Potentially adverse condition 3	P	NP	NP	NP	NP
Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.					
Potentially adverse condition 4	P	NP	NP	NP	P
Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.					
MAJOR CONSIDERATION 3: THE COST OF DEVELOPING AN ADEQUATE INFRASTRUCTURE BETWEEN THE SITE AND THE NEAREST NATIONAL TRANSPORTATION NETWORK					
Favorable condition 1	NP	P	P	P	P
Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:					
(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.	NP	N P	P	NP	NP
(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.	NP	NP	P	NP	NP
(iii) Cuts, fills, tunnels, or bridges are not required.	NP	NP	P	NP	NP
(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.	NP	P	P	P	P
(v) Such routes bypass local cities and towns.	NP	P	P	NP	P

Table 7-15. Guideline-condition findings by major consideration—transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: THE COST OF DEVELOPING AN ADEQUATE INFRASTRUCTURE BETWEEN THE SITE AND THE NEAREST NATIONAL TRANSPORTATION NETWORK (Continued)					
Favorable condition 2	NP	NP	P	NP	P
Proximity to local highways and railroads that provide access to regional highways and railroads, and are adequate to serve the repository without significant upgrading or reconstruction.					
Potentially adverse condition 1	P	P	NP	P	P
Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.					
Potentially adverse condition 3	P	NP	NP	NP	NP
Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.					
Potentially adverse condition 4	P	NP	NP	NP	P
Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.					
MAJOR CONSIDERATION 4: THE COSTS ASSOCIATED WITH TRANSPORTING THE SPENT FUEL AND HIGH-LEVEL WASTES TO THE SITE					
Favorable condition 4	NP	NP	NP	NP	P
Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.					
Favorable condition 5	NP	NP	NP	P	NP
Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.					
Favorable condition 6	P	P	P	P	P
Availability of regional and local carriers-truck, rail, and waste-which have the capability and are willing to handle waste shipments to the repository.					

7 0 1 6 8 3 1 5 4 5

Table 7-15. Guideline-condition findings by major consideration—transportation[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 4: THE COSTS ASSOCIATED WITH TRANSPORTING THE SPENT FUEL AND HIGH-LEVEL WASTES TO THE SITE (Continued)					
Favorable condition 7					
Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.					
Favorable condition 9	P	P	P	P	P
A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.					

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

the people living near the site will be most significantly affected, but they also recognize that the hazards and impacts of transporting wastes are national in scope. Because the DOE's main goal in transportation is safety, and the guidelines emphasize the role of safety, transportation safety is the most important consideration in evaluating the sites.

The transportation of radioactive materials during the past 40 years has been accomplished with an exemplary record of safety. Models that are used to estimate the radiological risks of transportation tend to generate extremely low expected-risk values for the public because they rely on historical data. When relative terms like "high" or "moderate" are used in this evaluation, they must be considered in the context of the low overall radiological risk from transportation. The nonradiological risk is calculated under the assumption that the probability of accidents for radioactive-waste shipments can be represented by accident statistics for general commerce. The DOE believes that these accident statistics will overestimate the actual number of deaths and injuries. Other factors being equal, the site with the smallest radiological hazard will also have the smallest nonradiological hazard.

Since the principal contributing factor in determining risk is the distance traveled, a better site for this consideration is one that is close to the sources of spent fuel and high-level waste. Other contributing factors that increase the favorability of sites are access and local routes that avoid population centers, flat local terrain with good visibility, and regional weather conditions that rarely cause hazardous road conditions. It should be noted that, regarding weather conditions, the DOE needs additional information before determining the comparative favorability of the sites. In contrast, less favorable sites are distant from waste sources, must be reached by routes that pass through population centers or rugged terrain, and are located in regions where weather conditions often cause hazardous road conditions. A summary of transportation risk and cost calculations is presented in Table 7-16; the reader is referred to Appendix A for more-extensive analytical results. Table 7-17 presents the factors used to evaluate disruptions of the environment and the cost of infrastructure. A summary of the evaluation for each site follows.

Davis Canyon is centrally located in the large region defined by the five nominated sites, but it is more difficult to reach because of its remote and rugged setting. Access from existing highways and railroads is extremely difficult, and there is a potential for landslides that could interrupt or jeopardize shipments. A long stretch of noninterstate highway must be traversed before reaching the site. From a national perspective, the relative risk of transporting to Davis Canyon is moderate to high, but that risk has to be considered along with the potential hazards near the site that could further reduce the overall level of safety. However, the added risk associated with hazardous local access to the site is somewhat offset by the remoteness of the site and the low population density in the area.

The Deaf Smith site is convenient to major national highways. The distance from sources of spent fuel is low to moderate, and, as shown in Table 7-16, the level of relative safety is therefore moderate to high. The terrain surrounding the site is generally flat and poses no safety hazard. The population density around the site is low to moderate.

Table 7-16. Summary of transportation risks and costs

Parameters	Davis Canyon	Deaf Smith	Hanford	Richton	Yucca Mountain
Risk[a]					
100% truck					
Radiological	9.5	7.9	12	6.3	11
Nonradiological	30	24	39	19	36
100% rail					
Radiological	0.3	0.2	0.3	0.2	0.3
Nonradiological	2.6	2.1	3.2	1.8	3.0
Number of interchanges	3	2-4	2-4	2-4	1-2
Total shipment-miles[b]					
100% truck	145.1	121.4	186.7	96.4	176.8
100% rail	25.5	21.7	33.3	17.7	31.1
Number of interchanges[c]	3	2-4	2-4	2-4	1-2
Cost[d]					
100% truck	1,305	1,127	1,615	936	1,538
100% rail	1,207	1,122	1,376	982	1,345

[a]Number of fatalities during the preclosure period.
[b]One-way million miles.
[c]Within the transportation study area.
[d]Millions of 1985 dollars.

Table 7-17. Factors used to evaluate disruption of the environment and cost of infrastructure

Parameter	Davis Canyon Truck/Rail	Deaf Smith Truck/Rail	Hanford Truck/Rail	Richton Truck/Rail	Yucca Mountain Truck/Rail
Access route					
Miles	25/38-54	1/25-35	<3/<3	4/26	16/100
Cost[a]	79/141-269	1/21-44	<6[b]	3/16	12/151
Upgrade					
Miles	64-68/0	4/0-13	0/0	23/0	0/0
Cost[a]	15-35/0	1/<10	0/0	6/0	0/0
Distance from end of access route to major highway or mainline rail	64-173/30-36	14/0-13	0/48	22/0	0/0
Need for tunnels	Yes	No	No	No	No
Need for bridges	Yes	Yes	No	Yes	Yes
Need for Federal condemnation	Yes	Yes	No	Yes	No
Terrain	Very rugged	Generally flat	Generally flat	Gently rolling	Gently sloping

[a]In millions of 1985 dollars.
[b]Total cost for truck and rail transportation.

Since the Hanford site is the most distant from the large majority of spent-fuel sources, it has the highest relative risk from a national perspective. The introduction of a second repository reduces the effect of distance on the overall transport risk (for a more complete discussion of the effect of a second repository see Appendix A, Section A.11). Transportation safety near the site is considered to be relatively high because of the flat terrain and the good existing transportation network. The population density in the area is moderate.

The Richton site is favorable for the transportation-safety consideration because it is closer to the sources of spent fuel than the other sites. National transportation risks are therefore reduced, and the relative level of transportation safety is high. The site would be more favorable if there were fewer local towns and cities were nearby; however, with the construction and upgrading of the local access routes, local safety should be high as well.

Yucca Mountain is easily accessible, but it is far from most sources of spent fuel. The local rail network that will be developed will effectively bypass Las Vegas. Local roads provide good access to the interstate highway system. One potentially hazardous feature of the access routes is their proximity to an Air Force bombing range. Although this is not expected to present a significant risk, some additional safeguarding of shipments may be required. The local terrain presents no hazards.

Environmental disruption. The second major consideration accounts for the environmental impacts caused by improving the existing infrastructure and constructing new access routes to the site. Though not as important as the first consideration, the potential for environmental disruption has much significance. For example, transportation operations and the development of access routes might adversely affect sensitive species on a large scale (over many miles), and the aesthetic quality of the region may be reduced by the construction of road and rail routes. This consideration reflects the focus in the guideline on local conditions around the site. Effects on the environment along national highways and railroads were considered when those networks were developed for regular commercial traffic. In this respect, the incremental environmental impacts of transporting radioactive waste are not considered to be significant on a national scale.

A contributing factor for this consideration is whether a site requires access routes that would disrupt the environment. Table 7-17 lists the major factors that are considered in evaluating the potential for environmental disruption. A more favorable site would be one that does not require the construction of lengthy access roads. Other qualities that would make a site better are access routes that do not conflict with current land-use plans; no requirements for cuts, fills, tunnels, or bridges; and disruptions that would affect the least number of people. A less favorable site would require significant construction of access routes through pristine or unique environmental areas. Other qualities that reduce the favorability of a site are access routes that conflict with current land-use plans; a requirement for many cuts, fills, tunnels, and bridges; and the displacement of many people by the access route. A summary of the evaluation for each site follows.

Major construction of highways and railroads would be required to reach the Davis Canyon site. This new construction would disrupt previously undisturbed land and diminish the aesthetic quality of the area. The construction of access routes would require major cuts and fills as well as tunnels. The existing transportation network would also have to be improved.

Deaf Smith County is located on generally flat terrain that would not require major excavation during construction. Upgrading of the existing road is not expected to cause significant environmental impacts. A long segment of new track must be laid to reach the site, but the environmental disruptions would be minor.

For the Hanford site, the truck and rail access routes would be short, and little environmental disruption would result from constructing the access routes. No improvement in the existing transportation network is needed.

The Richton site is on generally flat terrain. Although a long railspur would have to be built to reach the site, it would follow an abandoned railroad right-of-way. The existing local road would have to upgraded for a significant length. A short length of new road would have to be built to reach the site. The environmental impacts of new construction are not expected to be significant.

To reach the Yucca Mountain site, a long railspur and a moderate length of new road would have to be constructed. A long bridge would also be necessary. The terrain is such that the construction of these routes will cause minimal environmental disruption.

Cost of transportation infrastructure. This major consideration addresses the cost of constructing and upgrading the access routes to the sites. Its importance is gained from the emphasis in the qualifying condition on the local infrastructure and access routes. It is not as important as the first consideration because the protection of health and safety is more important than reducing costs.

The cost of the transportation infrastructure is considered separately from the costs of transporting waste to the site. Table 7-17 presents a comparison of costs for the construction of new road and rail access routes and the upgrading of existing networks at each site.

A favorable site for this consideration is one that needs little, if any, repair or upgrading of access routes. Other qualities of a favorable site include no requirement for Federal condemnation for rights-of-ways, a flat terrain, low costs for rights-of-way, and absence of other local anomalous features that may increase costs. A less favorable site has a poorly maintained or no transportation infrastructure; if it does exist, it is a long distance from the site, thus requiring much new construction. Other qualities of a less favorable site are a mountainous terrain, high costs for rights-of-way, the need to secure rights-of-way by Federal condemnation, and other features that could require expensive mitigation.

Cost of transportation hardware and operations. The least important consideration is the cost of developing the cask fleet and shipping the waste to the repository. This consideration is not as important as the others because transportation costs are relatively insensitive to location, and the protection of health and safety is more important than reducing costs.

The cost of transporting spent fuel to the repository sites depends to some extent on distance; that is, it costs about as much to ship waste 1,000 miles as it does 500 miles. Other factors that can influence cost, at least as determined at this stage of investigation, provide little additional guidance for discriminating among sites. A summary of transportation costs is presented in Table 7-16.

Like transportation safety, transportation cost is also affected by decisions about the configuration of the waste-management system, such as the second repository. The effect of the second repository is considered as quantitatively as possible.

A favorable site is one that is close to the sources of waste, is not subject to weather that will interfere with access to the repository, is served by existing carriers, is located in an area with emergency-response capabilities, is not located near communities that impose legal impediments to transport, and is served by rail routes that require few crew changes. A less-favorable site has characteristics that are the converse of the above factors.

Summary of comparative evaluations

The Richton site is the leading site for the major considerations that address transportation safety and the cost of transportation hardware and operations; it is the second most favorable site with respect to environmental disruption and the cost of the infrastructure. Because of the paramount importance assigned to transportation safety, the Richton site is the most favorable. The Deaf Smith site is distinguished from Richton mainly by being farther from the sources of the waste. The Hanford site is less favorable from a nationwide transportation perspective because it is the farthest from the sources of the waste. Local conditions at Hanford, however, are highly favorable in terms of safety, cost, and environmental disruption. Yucca Mountain, which is about equal in favorability to Hanford, is far from the sources of waste and would require major construction of access routes. Davis Canyon is the least favorable site for this guideline. Although it is moderately far from the sources of the waste, it is not readily accessible because the terrain in the area is very rugged. Moreover, major construction of highways and railroads is required, and it would cause significant environmental impacts.

7.3.2.2 System guideline on environment, socioeconomics, and transportation

Ranked second in importance in the preclosure system guidelines is environment, socioeconomics, and transportation. The pertinent system elements for environment, socioeconomics, and transportation (10 CFR 960.5-1(a)(2)) will, in general, consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by such activities; (3) the transportation infrastructure; and (4) the potential mitigating measures that can be used to achieve compliance with this guideline. To provide a comparative context for understanding the evaluation of this system guideline in Chapter 6, this section presents a brief summary of the evaluation of each site in terms of the system elements.

At Davis Canyon, the level of suspended particulates and gaseous emissions will increase during repository construction and operation. However, the concentrations of total suspended particulates (TSP) and nitrogen dioxide during all phases would be below the national ambient air quality standards (40 CFR Part 50). Construction lighting may have an effect on skyglow in the vicinity of the site. Repository construction and operation would increase the levels of noise, which may be heard in the Canyonlands National Park. It is expected that direct impacts on cultural resources during siting and construction can be minimized. Indirect impacts would not result in a loss of significant amounts of cultural information.

The site would not intrude on nearby dedicated lands. Transportation access to the Newspaper Rock State Historical Monument and the Canyonlands National Park would be temporarily disrupted. No unique aquatic or terrestrial habitat is likely to be significantly affected by the repository. The overall visual impacts of the repository would not be significant away from the immediate vicinity of the repository, except along Utah 211 and from the Davis Canyon Jeep Trail. The surface facilities would not be visible from any scenic view points or key observation points in Canyonlands National Park. A repository in Davis Canyon would, however, cause a significant adverse visual impact as viewed from the upper reaches of Davis Canyon in the park. Each of the four alternative rail corridors would create significant visual-contrast impacts from two to three key observation points in the area; none of these is inside the park.

Cumulative impacts on the Canyonlands National Park include shared traffic on Utah 211 (during site characterization), increased particulates and noise at the edge of the park, visibility of the site from Davis Canyon at the park boundary, sky brightness at night, and the potential of nearby industrial development. The impact of episodic noise intrusion on solitude in the park would be significant, but of short duration. During repository operations, all impacts mentioned above will be eliminated or reduced in the sections of the park designated for scenic, cultural, or solitude enjoyment purposes.

At Davis Canyon, available labor supplies within commuting distance of the site are expected to be insufficient to meet the requirements of the repository. The projected number of persons (workers and families) expected to in-migrate into the area during peak employment is significant. This would result in significant population increases in the rural communities of Monticello, Blanding, and Moab.

The population increase would require additional community services and facilities. The need for expanded community services and facilities could result in financial burdens to host communities because increased revenues from project and worker expenditures may not immediately be available to finance these capital expenditures. The increased demand for labor could reduce local unemployment but also cause competition and decreases in the labor available for other sectors of the economy. Advance community-development planning and financial and technical assistance can lessen the impacts on affected communities. Increased tax revenues and business activity would contribute to mitigation in the long term. Significant population increases would also cause social changes within communities. Planning for additional protective, social, and cultural services can mitigate these changes.

Some temporary disruption in the existing vehicle-traffic flow can be expected, and some localized inconveniences experienced, during the construction of new transportation corridors and the upgrading of others. Depending on the alternative road and railroad routes selected for the repository and the time of year, some threatened and endangered species or their preferred habitats may be affected. The radiological risks of transportation appear to be small. Estimates indicate that the maximally exposed individual could receive up to 3 percent of the doses delivered by natural background radiation. It may be possible to provide new highway and rail routes that will not disrupt local cities and towns.

At the Deaf Smith site, the local areas would sustain increases in suspended particulates and nitrogen oxide emissions, particularly during site clearing and construction. Mitigation measures would limit any significant increases of suspended particulates to the immediate vicinity of the site. Preliminary modeling results indicate air quality can be maintained within regulatory standards. Short-term increases in sound levels will occur in areas around drilling sites and near truck-mounted generators during the site characterization. At the nearest residences, noise during some stages of construction could exceed EPA guidelines. Practical engineering measures can be used to prevent runoff and ground-water contamination from the salt pile at the site. Salt-handling and control measures would be used to minimize the deposition of wind-blown salt on adjacent lands.

The site is in an agricultural area that is heavily dependent on irrigation. While the repository would represent a water demand on a limited resource, the demand is less than that required to irrigate an equivalent area. Repository development will divert 5,760 acres from potential agricultural uses. The withdrawal of this land represents less than 1 percent of the total prime farmland in the county. Neither the site nor potential transportation corridors would intrude on any dedicated resource areas. No unique aquatic or terrestrial species are likely to be affected. Structures and equipment at the site during siting and construction would be visible but not visually atypical of the region. Depending on the distance, the visual intrusion will range from moderate to high.

At the Deaf Smith site, employment predictions indicate that the available labor supply within commuting distance to the site would not be sufficient to satisfy repository labor requirements, particularly during the peak employment periods. Some in-migration of workers is therefore likely. The area seems able to absorb the projected population changes without significant disruptions in housing and other community services. However, some increases in the demand for community services can be expected. Increased tax revenues and mitigation grants from the DOE will assist in providing required additional services.

There are several feasible highway and railroad access routes to the Deaf Smith site that do not irreconcilably conflict with Federally protected resource areas. These routes can be designed and constructed with available technology and will not require waste-transportation packaging standards more stringent than existing NRC and DOT regulations, nor the development of new transportation casks. A preliminary evaluation of operations over representative highways and railroads to the Deaf Smith site indicates that waste-transportation operations can be conducted over these routes without unacceptable risk to the public or impacts on the environment. Also, adequate protection for the public and the environment can be provided during both the construction of the access routes and during operation over those routes.

For the Hanford site, no adverse environmental impacts have been identified that cannot be mitigated. The site is not within any protected resource areas, and compliance with regulatory requirements should not be a problem. No federally recognized threatened or endangered species are known to use the site as a critical habitat. There are significant native American resources on the Hanford Site, but they are far enough from the repository location so that there would be no significant adverse impacts.

Projected employment and population growth associated with the repository could be readily assimilated by the area. A technically qualified work force (except for miners) is located in the Tri-Cities and surrounding area. Roads, schools, utilities, and housing are all expected to have the ability to accept additional people in the area without stress on community services and facilities.

Access routes to the site would have no undesirable features that would require unique design or construction methods or special features of transportation system components, including the transportation packaging. Risks to public health and safety of proposed access routes would be acceptably low, since these routes are short and pass through areas without population. The environmental impacts of transportation are expected to be acceptably low, since the access routes are short and do not pass through protected resource areas. Projected risks, costs, and other impacts of waste transportation have been considered in repository siting, and transportation operations would be conducted in compliance with applicable regulation.

At the Richton site, the residual air-quality impacts are acceptable because they are below secondary standards. Clearing and construction activities would increase ambient noise levels near the site. Engineering design and distance to the nearest residences in the area will mitigate these noise levels to acceptable levels.

The construction of shafts to the underground facility would require the penetration of aquifers. Engineering safeguards to prevent threats to this water source are a recognized necessity. Existing technology is adequate to provide the needed protection.

Engineering measures can be used to prevent runoff and ground-water contamination from the salt pile at the site. Salt handling and control measures would be used to minimize the deposition of wind-blown salt. No known cultural resources will be affected by project activities.

The site would not intrude on any dedicated land or recreational areas. Any potential transportation rights-of-way that may be required through land under the National Forest System would be sited on existing or abandoned rights-of-way, thus minimizing land disruption.

No unique aquatic or terrestrial species are likely to be significantly affected. The surface facilities will be visible to some areas in the vicinity of the site. However, the emplacement is not likely to affect any existing unique features of the area.

At the Richton site, Employment predictions indicate that the available labor supply within commuting distances to the site will not be sufficient to satisfy repository labor requirements, particularly during peak employment. Some in-migration will therefore occur. Job-training programs can provide opportunities of employment for area residents, thus decreasing in-migration. The area seems capable of absorbing the projected population change without significant disruptions in housing and other community services. However, some increased demand for community services can be expected. Increased tax revenues will be received by State and local government. The town of Richton will experience impacts. This population increase would require expanded community services and facilities and may cause social changes in the town of Richton. Advanced community-development planning can lessen these impacts.

Some temporary disruption in existing vehicular traffic flow can be expected, and some localized inconvenience may be experienced during the construction of new transportation corridors and upgrading of others. The radiological risks of waste transportation appear to be small. Estimates indicate that the maximally exposed individual could receive up to 5 percent of the dose delivered by normal background radiation. Needed new highway and rail routes can be provided without disruption to local cities and towns.

At Yucca Mountain, the potentially significant adverse environmental impacts include (1) the destruction of approximately (1,608 acres) of desert habitat; (2) fugitive-dust emissions from surface preparation, excavation, and manipulation of spoils piles; (3) vehicle emissions from waste transport, personnel transport, and materials transport and the operation of construction equipment; and (4) radioactive-material releases during (a) repository excavation (e.g., from naturally occurring radon), (b) normal repository operation, and (c) accidents. Potential impacts on surface and ground water are considered insignificant, chiefly because there is no perennial surface water in the area, and ground water is several hundred meters beneath the repository horizon. A permanent land withdrawal would be required if the Yucca Mountain site is selected for repository development, and the reservation of water rights is explicit in such an action. Studies to date suggest that aquifers underlying the proposed locations of the surface facilities can produce large quantities of water for long periods without lowering the regional ground-water table. Other potential impacts, such as the diversion of natural runoff and the leaching of materials from excavated rock, are being considered in the repository design, and they are not expected to pose significant environmental problems.

During repository construction, the maximum estimated ambient concentrations of particulates, carbon monoxide, and the oxides of sulfur and nitrogen are not expected to exceed the air-quality limits of 40 CFR Part 50 (1983). Assuming the repository is subject to the "prevention of significant deterioration" provisions of the Clean Air Act Amendments of 1977, the predicted pollutant concentrations would violate none of the applicable standards.

Negative impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area are not expected to be significant for repository siting, construction, operations, and decommissioning at Yucca Mountain.

The affected area, including the Las Vegas Valley, has the ability to absorb the repository-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

Although community-specific service and housing demands could increase at rates proportional to the maximum 1-year community-population-growth rates estimated with the repository, these rates are generally within the range of those experienced historically by the urban communities and their municipal service providers. Because the unincorporated towns nearest the Yucca Mountain site have limited capability for community services, the potential population growth in these communities would generally impact county-wide service providers. These service providers are more likely to have resources for managing growth. In addition, the community-level growth rates estimated for the unincorporated towns are generally within the range of those experienced historically by Nye and Clark Counties. The work force in southern Nevada is sufficiently large to site, construct, and operate a repository at Yucca Mountain. Although an adequate total work force may be available for a repository at Yucca Mountain, the available work force with mining skills would be inadequate, and the available construction work force may also be inadequate. A repository at Yucca Mountain would increase employment and business sales in southern Nevada. Community services and government revenues are likely to increase.

For rail access to Yucca Mountain, a rail line extending approximately 100 miles from the existing mainline rail facilities at Dike Siding has been proposed. This route would be entirely on lands administered by the DOE and the U.S. Department of the Air Force and public-domain lands under the jurisdiction of the Bureau of Land Management. The terrain over which the rail line would cross is gently sloping. No tunnels and only a minor amount of excavation and fill would be required. A bridge would be required at Fortymile Wash several miles east of Yucca Mountain.

For highway access to the proposed site, a route is projected northward from U.S. Highway 95, originating approximately 0.5 mile west of the intersection of U.S. Highway 95 and Nevada State Route 373. The roadway access would be constructed on federally controlled lands that slope gently and would pose no significant engineering problems. No tunnels and only a minor amount of excavation would be required. Some minor drainage control measures and a bridge spanning Fortymile Wash would be required. The bridge would accommodate both the railroad and trucks. Between Las vegas and Mercury U.S. Highway 95 is a four-lane divided highway; it is a two-lane highway from Mercury to the access road near the intersection of U.S. Highway 95 and Nevada State Route 373. A requirement for significant upgrading of this regional highway is unlikely.

The evidence does not support a finding that any of the sites is not likely to meet the qualifying condition for environment, socioeconomic, and transportation.

7.3.3 EASE AND COST OF SITING, CONSTRUCTION, OPERATION, AND CLOSURE

7.3.3.1 Technical guidelines

The four technical guidelines in this group address the surface characteristics of the site, the characteristics of the host rock and the surrounding strata, hydrologic conditions, and tectonics. These guidelines are concerned with the ease and cost of siting, constructing, operating, and closing the repository.

7.3.3.1.1 Surface characteristics

The qualifying condition for surface characteristics is as follows:

> The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in §960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.

Major Considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-18), there are two major considerations that influence the favorability of the sites with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the potential for flooding the surface or underground facilities and (2) the characteristics of the terrain.

Evaluation of sites in terms of the major considerations

Potential for flooding surface or underground facilities.

This consideration is derived from the potentially adverse condition. It is important because the effects of flooding can be significant design considerations for cost and safety. The potential for, and the frequency of, flooding depend on the terrain and drainage of a site. Contributing factors are the location and likelihood of flooding from natural causes at the surface or underground facilities, the failure of man made surface-water impoundments, and the failure of engineered components of the repository. A summary of the evaluation for each site follows.

At the Davis Canyon site, a portion of the repository operations area lies within the flood plains of the 100-year and the probable maximum flood. There are no surface-water impoundments whose failure could flood the surface facilities, and there are no known surface characteristics that could cause the failure of engineered repository components. The potential for flooding would be reduced by using fill to elevate the site and constructing a lined flood-control channel.

Parts of the Deaf Smith site lie in the flood plains of the 500-year and the probable maximum flood, but no safety-related facilities would be

Table 7-18. Guideline-condition findings by major consideration--surface characteristics[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL FOR FLOODING OF SURFACE OR UNDERGROUND FACILITIES					
Potentially adverse condition					
Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.	P	P	P	P	P
MAJOR CONSIDERATION 2: TERRAIN CHARACTERISTICS					
Favorable condition 1					
Generally flat terrain.	NP	P	P	P	P
Favorable condition 2					
Generally well-drained terrain.	P	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

threatened by either flood. There are no surface-water impoundments that could flood the surface facility, and surface characteristics should not lead to failures of engineered repository components. Any effects of potential flooding would be mitigated by filling during construction.

The elevation of the Hanford site protects it from the probable maximum flood of the Columbia and Yakima Rivers, including both natural flooding and dam-breached floods. A shallow probable maximum flood could occur in the southwestern portion of the site along the drainage channel of the intermittent Cold Creek. The duration of such a flood would be short, and its effects could be mitigated to preclude any danger to the workers or to the surface and subsurface facilities.

During an estimated probable maximum flood at the Richton site, the head waters of the Fox Branch river could flood the area proposed for surface facilities. There are no existing or planned man-made surface-water impoundments in the vicinity of the Dome. It is assumed that Fox Branch would be diverted and channeled around the surface facilities and that grading and fill operations would raise the elevation of the site area above the flood plain.

At the Yucca Mountain site, the exploratory shaft would be located in a wash within a flood plain that would be affected by sheet and debris flow. Parts of the candidate locations are in an area that would be affected by the 500-year and the regional maximum floods. There are no existing or planned man-made surface-water impoundments near the site that could flood the surface facilities. Some engineering measures would be required to mitigate the impacts of the probable maximum flood. The hazards of sheet and debris flow at the exploratory shafts could be mitigated by measures like channel lining or diversion.

Terrain characteristics. This consideration addresses the effects of the terrain and drainage characteristics of a site on repository construction, operation, and closure. This consideration is derived from the first and second favorable conditions. It is less important than the first consideration because the characteristics of the terrain are more closely related to the ease and cost of construction than to safety and can generally be mitigated more readily than conditions that could cause flooding.

The contributing factors for this major consideration are the terrain and drainage characteristics of the site, the potential for landslides, and soil characteristics. A summary of the evaluation for each site follows.

The area around the Davis Canyon site is characterized by steep canyons and rugged terrain. Though the terrain at the surface facilities is quite flat, the terrain through which the access roads and railroad would be constructed is rugged. Existing drainage would be rechanneled around the surface facilities during construction. Soils are likely to be well drained, with low water retention since their parent materials are mainly sandstones and siltstones.

The surface of the Deaf Smith site is nearly flat, sloping eastward less than 1 percent. Topographic features include small, internally drained lake basins (playas) and narrow stream valleys that carry surface water after rainstorms. Soils appear to be acceptable for a large grading operation during repository construction.

The Hanford site is surrounded by an area of generally flat terrain for a radius of nearly a mile. The lack of surface-runoff features suggests the relatively coarse surficial sediments are effective in keeping the surface well drained and preventing surface-runoff features from developing north and east of the Cold Creek flood plain.

The Richton site is surrounded by generally flat terrain, with slopes of 3 to 4 percent and locally up to 10 percent. The soils are generally well drained, though small temporary ponds and marshy areas may form in the area immediately after a heavy rainfall. Soils appear to be acceptable for large grading operations during repository construction.

At Yucca Mountain, potential locations for the surface facilities are on the eastern side of the mountain. All are generally flat and covered with alluvium derived from adjacent highlands. The surface slope at these locations is less than 5 percent and in several places less than 3 percent. The exploratory-shaft facilities would be built within a wash that is partly surrounded by rugged terrain. Yucca Mountain has a well-established drainage system because of its porous alluvial soils and eastward-dipping slopes.

Summary of comparative evaluation

The most favorable site is Deaf Smith where only small parts of the site would be affected by the probable maximum flood. At Hanford, which is slightly less favorable, the probable maximum flood may reach portions of the surface facilities. Both the Deaf Smith and the Hanford sites have flat terrain that is generally well drained.

The Richton and the Yucca Mountain sites are somewhat less favorable than Deaf Smith and Hanford. At Richton site, the surface facilities would be located in the flood plain of the probable maximum flood, but the potential for flooding could be reduced by diverting the Fox Branch stream. Ponds may form after a heavy rainfall because the site is on flat terrain that is not well drained. At Yucca Mountain the exploratory-shaft facilities would be in a wash that is subject to sheet-and-debris flow and surrounded by rugged terrain. Parts of the candidate locations for the surface facilities may be within the flood plains of the 500-year and regional maximum floods. Although the surface facilities would be built on flat terrain, the site is well drained.

The Davis Canyon site is the least favorable for this guideline. The surface facilities at Davis Canyon would be within a 100-year flood plain, and the area is surrounded by steep canyons and rugged terrain. More-extensive engineering measures, such as channeling and drainage diversion, would be necessary to mitigate the impacts of a 100-year flood.

7.3.3.1.2 Rock characteristics (preclosure)

The qualifying condition for preclosure rock characteristics is as follows:

> The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in Section 960.5-1(a)(3) can be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-19), there are three major considerations that influence the favorability of sites with respect to the qualifying condition. In order of decreasing importance these considerations, are (1) in situ conditions that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure; (2) in situ conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and the underground facility, and (3) flexibility in selecting the location and configuration of the underground facility.

Evaluation of sites with respect to major considerations

Safety hazards and difficulties. This consideration includes in situ conditions that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related to the qualifying condition through concern about safety hazards to workers and the costs and technical feasibility of mitigating difficult conditions and safety hazards. It is derived from the second favorable condition and the third, fourth, and fifth potentially adverse conditions. Because of its concern with the safety of workers, this is the most important of the considerations related to this guideline. A summary of the evaluation for each site follows.

At Davis Canyon, the mechanical properties of the salt are such that no significant safety hazards from rock instability are expected. A significant safety hazard is the potential for the presence of combustible gas. Although there is no direct evidence that such gas is present at the site, experience in salt mines at other locations suggests that it may occur. The hazards from gas can be mitigated by following safety procedures and providing adequate ventilation. The requirements for artificial rock support are expected to be relatively minor (only occasional bolting) because of the apparent massiveness of the salt and the lack of nonsalt interbeds in the host rock. Also, the presence of any carnallite in the salt should not require increased artificial support since no differences in rock strength have been observed between Paradox Basin salt and carnallite during preliminary testing. However, maintenance of underground openings may be required because of salt creep at

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Table 7-19. Guideline-condition findings by major consideration--rock characteristics (preclosure)[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: SAFETY HAZARDS OR DIFFICULTIES DURING REPOSITORY SITING, CONSTRUCTION, OPERATION AND CLOSURE, INCLUDING RETRIEVAL					
Favorable condition 2					
A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation and closure.	NP	NP	NP	NP	P
Potentially adverse condition 3					
Geochemical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.	P	P	NP	P	NP
Potentially adverse condition 4					
Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.	P	P	P	P	NP
Potentially adverse condition 5					
Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.	P	P	P	P	NP
MAJOR CONSIDERATION 2: ENGINEERING MEASURES BEYOND REASONABLY AVAILABLE TECHNOLOGY					
Potentially adverse condition 2					
In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: FLEXIBILITY IN LOCATING THE REPOSITORY WITHIN THE HOST ROCK					
Favorable condition 1					
A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration and location of the underground facility.	P	NP	P	P	NP

Table 7-19. Guideline-condition findings by major consideration--rock characteristics (preclosure)[a,b] (continued)

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 3: FLEXIBILITY IN LOCATING THE REPOSITORY WITHIN THE HOST ROCK (Continued)					
Potentially adverse condition 1					
A host rock that is suitable for repository construction, operation and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.	NP	P	NP	NP	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

the candidate horizon. Salt creep will gradually reduce the size of underground openings, and, if significant, may require reexcavation to maintain minimum required dimensions. Salt creep could be a major factor if the waste needs to be retrieved, because it could cause difficulties in maintaining room stability and emplacement holes. However, available information indicates that the salt at Davis Canyon should have a relatively low rate of creep during the duration of the preclosure period.

At the Deaf Smith site, possible safety hazards are the potential for mine-roof instabilities, water inflow down the shaft from aquifers above the repository, and the presence of combustible gas. Interbeds in the salt above the underground openings may cause mine-roof instabilities. Rock falls can be prevented by adequate artificial supports. Water inflow from overlying aquifers can readily be prevented through ground-treatment and shaft-sealing techniques. Although there is no direct evidence that combustible gas is present at the site, experience in salt mines at other locations suggests that it may occur. The hazards from such gas can be mitigated by following safety procedures and providing adequate ventilation. The only artificial rock support required at the site is expected to be regular rock bolting, which will be needed to minimize mine-roof instabilities caused by interbeds in the roof. As at Davis Canyon, maintenance of underground openings may be required because of salt creep. Available information indicates that the salt at the Deaf Smith site would creep at a moderate rate during the duration of the preclosure period.

The safety hazards at the Hanford site are the potential for rock instabilities, large water inflows, high temperatures in the underground facility, and the presence of combustible gas. The high-stress conditions and high rock strength of the basalt suggest a possibility for rock bursts or other hazardous rock movements. However, preliminary evaluations indicate that such bursts are not likely to occur because of the closely jointed nature of the dense interiors, low extraction ratios, and the installation of rock-support systems. Regularly spaced rock bolting and shotcrete over wire mesh would probably be used at Hanford to support the underground excavations, but the extent of needed artificial supports is uncertain because of a lack of experience under similar conditions and a lack of understanding of the impact of thermally induced stress in the emplacement rooms. The high underground temperatures are not expected to cause a significant deterioration of support or instability of the rock. The basalt should not creep significantly, but maintenance, which is typical of deep hard-rock excavations, will probably be required. The potential for large water inflows can be reduced by probing with exploratory boreholes and mitigated through ground treatment and other methods. Combustible gas may be present as it comes out of solution from the ground water. Although the expected quantity of gas is uncertain, the hazards from the gas can be mitigated by following safety procedures and providing adequate ventilation. High temperatures (120°F) in the host rock also pose a potential hazard to workers, but this hazard can be mitigated by providing ventilation, protective clothing, and artificial cooling. There is a potential for minor difficulties in waste retrieval if the emplacement holes do not remain stable during the retrieval period.

At the Richton site, the mechanical properties of the salt are such that no significant safety hazards from rock instability are expected. A possible safety hazard is the potential presence of combustible gas. Although there is no direct evidence that gases are present, experience in salt mines at other locations indicates that it may occur. Hazards from gas can be mitigated by following safety procedures and providing adequate ventilation. On the basis of experience with artificial support in salt mines in the Gulf Coast region, the artificial support required at the Richton Dome is expected to be widely spaced rock bolting. As with the other salt sites, significant maintenance of underground openings may be required because of salt creep. However, the magnitude of creep over long time periods is highly uncertain at the Richton Dome, as it is at the other sites. Available information indicates that salt at the Richton Dome would undergo a moderate rate of preclosure creep.

At Yucca Mountain, safety hazards are limited to the potential for rock falls. The rock strength of welded tuff and in situ stresses are favorable. However, the fractured nature of the tuff could cause rock falls in underground openings. Faults encountered in the underground facility may also contribute to local instabilities because of the poor quality of rock associated with brecciated fault zones. The potential for rock falls can be mitigated through the use of appropriate artificial supports for the underground openings. On the basis of previous excavation at the Nevada Test Site, the expected artificial support requirements at Yucca Mountain are regularly spaced rock bolts with steel mesh covering the rock surface. Occasional supplemental bolting or shotcrete may be required in areas of poor-quality rock, but these requirements are minimal compared with the ground support needed in similar underground construction projects. Since the tuff does not creep, little deterioration of the rock and the artificial support is expected because of time and temperature changes. Fractures in the tuff could complicate retrieval, especially if waste is emplaced in long horizontal holes. Such difficulties could be avoided by providing liners for the emplacement holes.

Complexity of engineering measures. This consideration includes in situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of shafts and underground facilities. The complexity of engineering measures relates directly to the concern in the qualifying condition with technical feasibility. This consideration is derived from the second potentially adverse condition. Although the success of repository construction depends on its technical feasibility, the complexity of engineering measures is second in importance to the safety of personnel. A summary of the evaluation for each site follows.

At Davis Canyon, the construction of the shafts and underground facility is not expected to require engineering measures beyond existing technology. Shaft sinking, underground excavation, artificial support, and protection against any preemplacement safety hazards (such as gas or brine pockets) can be accomplished with technology that has been developed in the salt-mining industry.

At the Deaf Smith site, the shafts and underground facility would also be constructed with technology developed in the salt-mining industry. However, because the Ogallala aquifer lies above the repository at this site, stabilizing the ground for shaft sinking and providing effective water seals for the shaft liner would be more difficult. In addition, the presence of interbeds at the repository horizon would require additional artificial support in the underground facility.

Although the technology required to construct the underground facility at the Hanford site is reasonably available, constructing the repository shafts by blind hole drilling is at the limit of available technology. The shaft would be drilled in an environment that involves a difficult combination of depth, rock conditions, ground-water conditions, and stress conditions. Because shaft drilling in equivalent environments has not been attempted, a reliable data base is not available. Potential ground-water inflows, gases, and high rock temperatures can be managed with available technology, but the combination of conditions could require engineering measures that are more extensive than that usually required in underground construction.

At the Richton site, the shafts and the underground facility can also be constructed with technology developed in the salt-mining industry. A number of salt mines have operated in the Gulf Coast region, and the expected conditions (and the technology to handle those conditions) are relatively well known.

At Yucca Mountain, the construction of the shafts and the underground facility would not require engineering measures beyond existing technology. Construction experience at the G-tunnel on the Nevada Test Site and in other excavations in tuff, coupled with the unsaturated-tuff conditions, indicate that construction at Yucca Mountain should require proved engineering techniques.

Flexibility. Flexibility in selecting the depth, configuration, and location of the underground facility is related to the thickness and the lateral extent of the host rock--the concern of the qualifying condition. Derived from the first favorable condition and the first potentially adverse condition, this consideration is judged to be less important than worker safety and technical feasibility. A summary of the evaluation for each site follows.

At Davis Canyon, the host salt bed is expected to offer significant flexibility in locating the repository. Its thickness appears to be several times greater than necessary, and the available host rock appears to extend laterally for many kilometers. It also appears that there are no significant interbeds, impurities, or other stratigraphic or structural features within the salt bed that would limit this flexibility. However, this evaluation is based on a limited database for the site.

At the Deaf Smith site, flexibility is limited by the expected presence of interbeds in the host salt bed. Although the host salt bed is relatively thick, the interbeds in the salt restrict the vertical flexibility for locating the repository. In contrast, there is extensive lateral flexibility because the host rock appears to extend for many kilometers. This evaluation is based on geologic information obtained from boreholes near the site.

The Hanford site appears to offer restricted vertical but significant horizontal flexibility. The thickness of other basalt flows in the area varies significantly over short distances, and the predictability of the host-rock thickness at Hanford is uncertain because of a limited data base.

The host salt at the Richton site appears to offer significant flexibility. Flexibility is greatest in the vertical direction, with the salt dome extending for thousands of meters, but there is some lateral flexibility as well. Although the shape of the dome is relatively well known from boreholes and geophysical surveys, there is a potential for undetected and unfavorable internal structures in the dome that could limit flexibility.

There appears to be significant vertical flexibility to locate a repository at Yucca Mountain, but lateral flexibility may be limited by minor faults, a shallow overburden, or site anomalies. The lateral extent of homogeneous host rock outside the primary repository area has not been established.

Summary of comparative evaluations

Since Yucca Mountain is the most favorable site for the two most important considerations, it is the most favorable site for the preclosure guideline on rock characteristics. Yucca Mountain is expected to have the fewest safety hazards, and it would require only existing construction technology and minimal artificial support and maintenance. The limited host-rock flexibility does not outweigh the favorability of the other considerations.

Davis Canyon is relatively favorable for all the major considerations, but it is less favorable than Yucca Mountain. Although there is some potential for safety hazards and retrieval difficulties, and some maintenance would be needed, Davis Canyon would require only existing construction technology and offers significant flexibility in locating the underground facility. The salt at Davis Canyon is expected to creep at a slower rate than the salt at the Deaf Smith or the Richton site.

The Deaf Smith site is as favorable or only slightly less favorable than the Davis Canyon site for the major considerations. Because of the presence of interbeds, it may be more difficult to engineer the repository and maintain underground openings and waste-retrieval capability. The favorability of the site is further reduced by the limited flexibility for locating the underground facility and the faster rate of salt creep in comparison with the other salt sites.

The Richton site is generally favorable for all considerations, but it is less favorable than Davis Canyon for host-rock flexibility and less favorable than both of the other salt sites with respect to the potential for combustible gas. Also, the salt at Richton is expected to creep at a faster rate than the salt at Davis Canyon.

Hanford is generally less favorable than the other sites for the most important considerations (safety hazards and difficulties, engineering measures) and more favorable for the least important considerations. The potential safety hazards and the engineering measures required for construction are the key considerations that make Hanford the least favorable site for this guideline.

7.3.3.1.3 Hydrology

The qualifying condition for the hydrology guideline is as follows:

> The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in 960.5-1(a)(3) to be met.

Major considerations

On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-20), there are three major considerations that influence the favorability with respect to the qualifying condition. These major considerations, in order of decreasing importance, are (1) the complexity of required ground-water-control measures, (2) the existence of surface-water systems that could cause flooding of the repository operations area, and (3) the availability of water for repository construction, operation, and closure.

Evaluation of the sites in terms of the major considerations

Complexity of required ground-water-control measures. This consideration includes ground-water conditions that could necessitate extensive and complex ground-water-control measures in shafts and drifts during repository siting, construction, operation, and closure. It relates directly to the qualifying condition by favoring hydrologic conditions that are compatible with repository construction, operation, and closure and will not compromise shaft liners and seals. This major consideration is derived from the first favorable condition and the potentially adverse condition. The complexity of required ground-water-control measures is the most important of the three considerations for hydrology because it has the greatest effect on the ease and cost of repository construction, operation, and closure. A summary of the evaluation for each site follows:

Table 7-20. Guideline-condition findings by major consideration—hydrology[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: COMPLEXITY OF REQUIRED GROUND-WATER CONTROL MEASURES					
Favorable condition 1					
Absence of aquifers between the host rock and the land surface.	NP	NP	NP	NP	P
Potentially adverse condition					
Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation and closure.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: EXISTENCE OF SURFACE-WATER SYSTEMS THAT COULD POTENTIALLY CAUSE FLOODING OF THE REPOSITORY					
Favorable condition 2					
Absence of surface-water systems that could potentially cause flooding of the repository.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 3: AVAILABILITY OF WATER FOR CONSTRUCTION, OPERATION AND CLOSURE					
Favorable condition 3					
Availability of the water required for repository construction, operation, and closure.	P	P	P	P	P

[a] Key: NA = not applicable; NP = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is not present at the site; P = for the purpose of this comparative evaluation, the favorable or potentially adverse condition is present at the site.

[b] Analyses supporting the entries in this table are presented in Chapter 6 of the environmental assessment for each site.

At the Davis Canyon site, rock units above the host rock and the host rock are generally of low permeability. Several minor aquifers with limited water-producing potential are present above the host rock. The small amounts of ground water that would be encountered during shaft sinking can be readily handled with standard engineering practice.

At the Deaf Smith site, an aquifer is present between the host rock and the ground surface. The potential for ground-water inflows during the sinking of shafts through the High Plains aquifer, the unconsolidated sediments above the repository, and the water-bearing interbeds in the host salt bed can be controlled with established technology, such as pretreatment by freezing. Little ground water is expected within the repository horizon.

At the Hanford site, a number of aquifers exist between the host rock and the ground surface. During shaft sinking, ground water would be controlled with established practices. After construction, seals associated with the shaft liner would protect the shafts and repository drifts from ground-water inflow. The construction of the repository may result in the penetration of water zones under high hydrostatic head. However, the potential for large, inadvertent water inflows can be reduced by probing with exploratory boreholes in advance of drifting to locate water zones under high hydrostatic head.

At the Richton site, several aquifers are present above the host rock and adjacent to the flanks of the dome. Control of ground water during shaft sinking through the sediments above the dome and caprock would require ground freezing because of potentially high ground-water inflows and the presence of unconsolidated sediments. Little water is expected within the dome.

At the Yucca Mountain site, there are no aquifers between the host rock and the ground surface. Because the repository would be located above the water table, no significant amounts of ground water are likely to be encountered in the shafts or underground workings.

Existence of surface-water systems that could flood the geologic repository operations area. This consideration includes ponds, lakes, streams, and manmade impoundments that could flood the underground workings during repository construction, operation, and closure, endangering the safety of workers and interrupting repository operations. It relates to the implied concern in the qualifying condition with the compatibility of surface-water systems with repository construction, operation, and closure. This consideration is derived from the second favorable condition and is considered second in importance because it is generally easier to manage the potential for surface flooding than underground ground-water inflows: standard engineering measures like dikes and berms can minimize the potential for flooding. A summary of the evaluation for each site follows.

At the Davis Canyon site, the area of the surface facilities could be inundated by the 100-year and the probable maximum flood. To reduce the risk of flooding, the site would be filled in to an elevation above the flood level, and control channels would be constructed to divert any flow around the site.

At the Deaf Smith site, minor flooding occurs within the controlled area, but there are no surface-water systems that could flood the restricted area. Although a small portion of the restricted area may intercept the flood plain of the probable maximum flood, there is considerable flexibility for locating surface facilities and shafts to avoid flooding.

At the Hanford site, the probable maximum flood of the Columbia and Yakima Rivers would not reach the repository operations area. The maximum flood of the ephemeral Upper Cold Creek could reach the area proposed for the surface facilities, but flooding would be shallow and short-lived, and it would not pose a significant hazard to surface or subsurface facilities. The 100-year flood of Cold Creek is not expected to reach the surface facilities.

The surface facilities at the Richton site would be located on high ground that is drained by Fox Branch and a tributary of Linda Creek. The present site of the surface facilities would be modified by filling in low-lying areas, constructing dikes, or diverting streams to prevent flooding of the surface and underground facilities.

At the Yucca Mountain site, each of the candidate locations for surface facilities is above the flood plain of the 100-year flood, but parts of these areas would be affected by the 500-year flood and the regional maximum flood. The proposed exploratory-shaft site in Coyote Wash may be subject to localized flooding and debris flow. However, the impacts of this infrequent, localized flooding can be mitigated by engineering measures like channel lining and drainage diversion.

Availability of water for repository construction, operation, and closure. This consideration relates to the availability of an ample source of ground or surface water for repository construction, operation, and closure. It is related to the concern in the qualifying condition about the compatibility of the geohydrologic setting with the ease and cost of construction and is derived from the third favorable condition. This consideration is third in importance because, although it affects the ease and cost of construction, it has a limited effect on the technical feasibility of construction, operation, and closure. A summary of the evaluation for each site follows.

At the Davis Canyon site, ample water for repository development is not available in the immediate vicinity of the site, but water could be purchased from the San Juan Water Conservancy District. The water supply may be taken from the Colorado River south of Potash, Utah, and piped 22 miles from the river to the repository site along the proposed railroad access route.

The availability of water at the Deaf Smith site may be limited because the High Plains aquifer could become depleted through normal irrigation use within the operating lifetime of the repository. Consequently, the underlying Dockum aquifer will be evaluated during site characterization to determine its suitability as a supplementary water supply.

At the Hanford, Richton, and Yucca Mountain sites, there is ample ground water in the immediate vicinity of the sites for repository construction, operation, and closure. There is little doubt that this water would be available for a repository at these three sites.

Summary of comparative evaluation

The Yucca Mountain site is the most favorable site for the preclosure hydrology guideline. It is the leading site for the most important consideration: the repository would be located in the unsaturated zone, and no significant amounts of ground water are likely to be encountered in the shafts and drifts. There is also ample water available for construction, operation, and closure from a source within the controlled area. Although there is a potential for flash flooding, standard drainage-control measures would protect against such flooding. Current engineering technology is more than adequate to handle the hydrologic conditions that are likely to be encountered at Yucca Mountain.

Davis Canyon is only slightly less favorable for the most important major consideration because little difficulty is expected in controlling ground water at the site. However, there is a potential for flooding, and water for the repository would have to be piped in from the Colorado River.

At the Richton site, shafts can be sunk with standard technology, but ground freezing would be required to control ground-water inflow; therefore, the Richton site is less favorable than Davis Canyon and Yucca Mountain for the most important major consideration. Ample water is available for repository construction, operation, and closure, but engineering measures would be required to divert surface drainage.

The Deaf Smith and the Hanford sites are least favorable for this guideline. At the Deaf Smith site, ground-water conditions would make shaft sinking more difficult and would require ground freezing. There is also uncertainty about the availability of ample water for the life cycle of the repository. However, there is no potential for flooding within the restricted area. At the Hanford site, there is a potential need for ground-water-control measures that are more complex and costly than those at the other sites. There is minimal potential for flooding the surface or subsurface facilities and an ample supply of water for construction, operation, and closure. However, the potential complexity of the required ground-water-control measures is judged to reduce the overall favorability of the Hanford site in comparison with Davis Canyon and Richton.

7.3.3.1.4 Tectonics (preclosure)

The qualifying condition for preclosure tectonics is as follows:

> The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in §960.5-1(a)(3) can be met.

Major considerations

The objective of the preclosure tectonics guideline is to ensure that a site is not likely to be affected by tectonic events of such magnitude that unreasonable or unfeasible engineering design features would be required. On the basis of the qualifying, favorable, and potentially adverse conditions for this guideline (see Table 7-21), two major considerations are identified that affect favorability with respect to the qualifying condition: (1) the potential for earthquake ground motion at the site and (2) the potential for faulting at the site. These major considerations are of about equal importance.

Evaluation of sites in terms of the major considerations

It is important to note that the third potentially adverse condition is not present at any of the five sites (see Table 7-19). The historical seismicity in the geologic setting was used as the basis of this evaluation because it is representative of earthquake potential for short periods of time, such as the preclosure period for the repository. Current understanding indicates that a seismic event of larger than historical magnitude is not likely (less than about 1 chance in 100) to occur during the operation and closure of the repository. This interpretation does not consider earthquakes that may be associated with design events or ground-motion estimates (the second favorable condition and the second potentially adverse condition) or evidence of active faults (the first potentially adverse condition). These are considered to be of low probability. However, as discussed below, the evaluation of ground-motion potential (first major consideration) does consider the earthquake potential of tectonic structures and faults, and data developed for the evaluation of the third potentially adverse condition.

The qualifying condition for the preclosure tectonics guideline also requires an assessment of the potential for igneous activity at each of the sites. On the basis of preliminary data, igneous activity is not expected to cause any adverse preclosure impacts at any of the sites, and therefore igneous activity is not discussed further in this section.

Potential for earthquake ground motion at the site. This consideration requires an evaluation of whether strong ground motion at the site could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related directly to the concern in the qualifying condition about the effects of tectonic phenomena and technical feasibility. It is derived from the favorable condition and the second and third potentially adverse conditions. This major consideration is about equal in importance to the expected impact of fault displacement. Although the likelihood of ground motion at a given site is generally higher than the likelihood of faulting, ground motion and faulting can both be significant design considerations.

Contributing factors for this major consideration include the historical earthquake record, evidence of man-induced seismicity, estimates of ground motion from historical and man-induced earthquakes, the correlation of earthquakes with tectonic structures and faults, and evaluations of the effects of ground-motion hazards on design. In addition, the evaluation of

Table 7-21. Guideline-condition findings by major consideration--tectonics (preclosure)[a,b]

Condition	Davis Canyon	Deaf Smith	Hanford	Richton Dome	Yucca Mountain
MAJOR CONSIDERATION 1: POTENTIAL FOR EARTHQUAKE GROUND MOTION AT THE REPOSITORY SITE					
Favorable condition					
The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.	NP	P	NP	P	NP
Potentially adverse condition 2					
Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.	NP	NP	NP	NP	NP
Potentially adverse condition 3					
Evidence, based on correlations of earthquakes with tectonic processes and features (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity.	NP	NP	NP	NP	NP
MAJOR CONSIDERATION 2: POTENTIAL FOR FAULT DISPLACEMENT AT THE REPOSITORY SITE					
Potentially adverse condition 1					
Evidence of active faulting within the geologic setting.	P	NP	P	NP	P

ground motion depends on the evaluation of potential surface faulting in the geologic setting. The potential for ground motion generally increases as the potential for faulting near the site increases. However, the ground-motion potential from all seismogenic sources cannot be evaluated individually: it must be considered collectively to accurately evaluate the potential for ground motion and associated uncertainties. A summary of the evaluation for each site follows.

At Davis Canyon, the estimated ground motion is not significantly smaller than that generally allowable for nuclear facilities. These estimates are based on the assumption that the maximum earthquake, which has a magnitude of 6.5, could occur at Shay Graben, the closest (10 miles) significant structure in the geologic setting. Ground-motion estimates associated with these faults are moderate compared with design values for nuclear facilities. Since 1979, microearthquake monitoring has detected no seismicity at the site. However, events with a magnitude of up to about 3.0 have occurred in the Paradox Basin. Although the seismic hazard appears to be low, the record of seismicity is limited. Man-induced seismicity may be occurring at one location in the Paradox Basin, but it is not firmly established. Estimates of ground motion will remain uncertain until the faults near Shay Graben and the Needles area and the potential for man-induced seismicity at the site are fully evaluated.

At the Deaf Smith site, there appear to be no Quaternary faults in the geologic setting, and the known faults are not associated with recorded seismic activity. The site has a very low potential for induced seismicity. Predicted ground motions are significantly smaller than those generally allowable for nuclear facilities. Quaternary faulting (i.e., the Meers fault) outside the geologic setting appears to be present along the Amarillo Uplift. Study of the Meers fault to determine its tectonic characteristics and earthquake potential may influence evaluations of the portion of the Amarillo Uplift in the Texas Panhandle. This may effect estimates of ground motion at the site, although the distance to the uplift is more than 30 miles. On the basis of a qualitative understanding of present conditions, projected ground motions are well below the level that is likely to cause significant damage to underground structures.

At the Hanford site, potential ground motions are not significantly smaller than those generally allowable for nuclear facilities. However, the ground motions associated with possible Quaternary faulting in the vicinity of the Hanford site are within reasonable design limits for nuclear facilities. An earthquake record of over 100 years shows the historical seismicity of the Columbia Plateau to be low to moderate. This is consistent with data from seismic monitoring initiated in 1969. Recurrence rates for moderate earthquakes (of a magnitude greater than 6 to 6.5) appear to exceed 10,000 years. Earthquakes are not currently associated with mapped geologic structures, nor do hypocenters align in a manner suggesting that there could be unmapped buried faults in the Pasco Basin. The impact and the likelihood of potential earthquake swarms at the repository site have not been determined. Although uncertainties exist, it is expected that the effects of subsurface ground motion can be mitigated by existing engineering measures.

At the Richton site, ground motion is expected to be significantly smaller than that generally allowable for nuclear facilities. Studies to date provide no evidence of active faulting during the Quaternary Period and no association of known faults with recorded seismic events within the geologic setting. The site is in an area of extremely low earthquake frequency, and there is little potential for induced seismicity. The nearest known earthquake epicenter is 45 miles away. On the basis of a qualitative understanding of present conditions, predicted ground motions are well below the level that could cause significant damage to underground structures. Uncertainty in estimates of ground motion is considered to be relatively low, primarily because the site is located in a region with a very low level of historical seismicity. However, there is some uncertainty about the southern extent of the New Madrid fault zone. This would likely result in more long-period motion than shaking from a maximum earthquake in the site's geologic setting.

On the basis of current knowledge, there is large uncertainty in the evaluation of potential ground motion at the Yucca Mountain site. Data on the age of the last movement, the total amount of movement during the Quaternary Period, and the extent of faulting within 1 to 5 kilometers of the site are limited, and the assessment of ground motion is preliminary. It is premature to place much confidence in estimates of ground motion until a more complete assessment can be made of the extent of faulting near the site and of the appropriate assumptions for such parameters as fault length, fault displacement, attenuation relationships, and earthquake potential. The brief historical seismic record at Yucca Mountain shows no earthquakes that have produced damaging ground motions, and current estimates of recurrence intervals for large earthquakes (greater than magnitude 7.0) in the geologic setting exceed about 25,000 years. Although estimates of ground motion for the surface and subsurface facilities are not expected to be significantly smaller than for other nuclear facilities, reasonably available technology is expected to be sufficient to accommodate the seismic design requirements. These requirements would be established during site characterization. This judgment is based on current knowledge of faults near the site. The maximum acceleration from ground motion induced by underground nuclear explosions is less than that from natural earthquakes. The reader is referred to Chapter 6 of the environmental assessment for Yucca Mountain for a description of the approach to be used in establishing the appropriate seismic design requirements.

Expected impact of fault displacement at the repository site. This consideration requires an assessment of fault-displacement potential that could lead to safety hazards or difficulties during repository siting, construction, operation, and closure. It is related directly to the concern in the qualifying condition about technical feasibility and the effects of tectonic phenomena. It is derived from the first potentially adverse condition and is equal in importance to the first major consideration. Although the likelihood of faulting at a site is generally lower than the likelihood of ground motion, the need to design for fault displacement can have a significant effect on the site's favorability. Successful construction experience where fault-displacement conditions exist is an important contributing factor to favorability. Contributing factors for this major consideration are the evidence and location of, and rates of movement on, Quaternary faults in the geologic setting. A summary of the evaluation for each site follows.

In the Paradox Basin, Quaternary faulting is suspected in the vicinity of the Davis Canyon site at both Shay Graben and the Needles fault zone. However, additional data are needed to determine whether these displacements are seismogenic or related to gravitational sliding, salt flow, or salt dissolution. These faults do not trend toward the repository operations area, and there is no known seismicity within the site boundaries. Thus, no impact is expected from fault displacement at the repository site. There is uncertainty associated with this conclusion because of the possibility that mining the repository could induce seismicity at the site.

Since no active surface faulting of Quaternary age has been recognized in the geologic setting of the Deaf Smith site, there is no expected impact from fault displacement. The geologic setting has experienced little or no tectonic activity during the Quaternary Period. The Meers fault, which appears to show evidence of recent activity, is outside the geologic setting.

Quaternary faults have been identified within the geologic setting of the Hanford Site, but they do not intersect the repository location. Active faults are not known to be present at the site. Since the site is away from areas of known or suspected surface faults and there is no significant seismicity within its boundaries, no impacts from fault displacement are expected. There is uncertainty associated with this conclusion because the potential effects of earthquake swarms on underground facilities are unknown.

Studies to date provide no geologic evidence of Quaternary faulting in the geologic setting of the Richton site. Growth faults, which are not generally associated with seismicity, may occur in the Mississippi salt basin. However, because the Mississippi salt basin is not considered to contain areas of active subsidence and is isolated from the area of the Gulf Coast that is associated with growth faults in the Wiggins Anticline, active growth faulting is not expected.

There are uncertainties in the data on the age of last movement and the total movement of faults at and near Yucca Mountain during the Quaternary Period. Since the area has been mapped and studied in sufficient detail, it is unlikely that major fault zones are undetected. New data may indicate 1 centimeter of fault displacement in the eastern Crater Flat area more recently than about 6,000 years ago. Estimated recurrence intervals for large earthquakes (magnitude 7.0 or greater) associated with surface faulting appear to be long (on the order of 25,000 years). Only minor seismicity has been detected near the site. These conditions suggest that the potential for fault displacement at the site is low during the preclosure period; thus, there are no expected impacts from fault displacement. Existing seismic design technology can accommodate small amounts of surface displacement if necessary.

<u>Summary of comparative evaluation</u>

The Richton site is the most favorable for the preclosure tectonics guideline. It is located in a region of extremely low ground motion and seismic hazard. Ground motion at the site is likely to be accommodated by reasonably available technology. No seismogenic faults have been identified in the geologic setting.

The Deaf Smith site is similar to the Richton site for the two major considerations, except for a slightly higher potential for ground-motion impacts from the Amarillo Uplift, which reduces its favorability. No seismogenic faults have been identified in the geologic setting, the ground-motion potential for the region is low, and ground motion at the site is likely to be accommodated with existing technologies. There is some uncertainty in the potential for ground motion, primarily because the impact of earthquakes on the Amarillo Uplift requires additional study.

The Davis Canyon and the Hanford sites are favorable with respect to the potential impacts of fault displacement. However, estimates of ground motion at both sites are uncertain because of Quaternary Period faults in the geologic setting and the potential for earthquake swarms at Hanford and man-induced seismicity at Davis Canyon. Although current estimates of ground motion for both sites are considered moderate, the seismic record qualitatively indicates that the seismic hazard for these regions is low. At Davis Canyon the closest known potential seismogenic fault is about 10 miles from the site, but this fault would not intersect the site.

At Hanford, the closest potential seismogenic faults are 6.2 to 7.4 miles from the site, but they, too, would not intersect the Hanford site.

Yucca Mountain is the least favorable site for both major considerations. A qualitative understanding of faulting near the site supports the conclusion that individual faults have long recurrence intervals (on the order of 25,000 years or more) for large earthquakes (magnitude 7.0 and greater). There are uncertainties with respect to the age of the last movement and the total amount of Quaternary movement on faults within 1 to 5 kilometers the site. Although estimates of ground motion are preliminary, it is expected that available technology could accommodate likely ground motion. Final estimates of ground motion will depend on the outcome of further seismic evaluations and the full assessment of nearby faults.

7.3.3.2 System guideline on the ease and cost of siting, construction operation, and closure

The third preclosure system guideline is ease and cost of siting, construction, operation, and closure. The pertinent elements are (1) the site characteristics that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; (3) written agreements between the DOE and affected States and affected Indian tribes and the Federal regulations that establish the requirement for these activities; and (4) the repository personnel at the site during siting, construction, operation, or closure. It is third in importance because it does not relate directly to the health, safety, and welfare of the public or the quality to the environment. A summary of the pertinent characteristics of the host rock at each site and estimates of the engineering, materials, services, and personnel costs are presented below for the salt, basalt, and tuff sites.

Total life-cycle cost estimates* for a repository in basalt (the Hanford site), salt (the Davis Canyon, Deaf Smith, and Richton sites), and tuff (the Yucca mountain site) are shown in Table 7-22. These estimates were developed as part of the DOE's annual evaluation of the adequacy of the fee (1 mill per kilowatt-hour) paid into the Nuclear Waste Fund for disposal services and do not represent final cost estimates. More definitive estimates will be completed when more-detailed designs and site-characterization data become available. The salt cost estimate was based on design parameters that are representative of a genenic salt site. Therefore, this estimate does not take into account site-specific differences that exist at each salt site.

Table 7-22 Repository cost estimates
(billions of 1984 dollars)

Site	D&E	Construction	Operation	Decommissioning	Total
Basalt	1.5	2.3	8.3	0.2	12.3
Salt[a]	1.8	1.6	4.9	0.2	8.5
Tuff	1.5	1.1	5.8	0.1	8.5

[a]All salt sites.

The major cost components identified in Table 7-22 are defined below

- Development and evaluation (D&E): Includes costs for all activities, excluding final design and construction, that are conducted before repository operation. These activities include site characterization, conceptual and license-application design, licensing, and technology development.
- Construction: Includes costs for final design and costs for the construction of all surface facilities and a limited number of underground waste-disposal rooms and corridors.
- Operation: Includes costs for the construction of most of the underground rooms and corridors and costs for the operation of the surface and underground facilities.
- Decommissioning: Includes cost for the decontamination and decommissioning of the surface facilities.
- Total: Represents the total life-cycle cost for a geologic repository and includes the sum of all the above cost components.

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*U.S. Department of Energy, Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program, DOE/RW-0024, Washington, D.C., April 1985.

The uncertainty that has been assigned to these estimates is based on engineering judgment and is ±35 percent of the total cost of the facility. This, coupled with a 10 to 40 percent contingency already built into the estimates, reflects the accuracy of preconceptual design from which the costs were derived. The exact contingency used depends on the complexity of the design of specific repository facilities or processes.

Salt repository

Host-rock depth. The horizons of the host rock at the Davis Canyon, Deaf Smith, and Richton sites are 3,000, 2,700 and 2,100 feet below the surface, respectively. The horizon assumed for the generic salt cost estimate is 3,000 feet below the service. This is a relatively deep horizon when compared with other siting alternatives.

Rock conditions and tunnel stability. At the Davis Canyon and Richton sites, the artificial rock support required is expected to be minor (only occasional rock bolting) because of the apparent massiveness of the salt and the absence of nonsalt interbeds in the host rock. However, significant maintenance may be required for underground openings because of salt creep. Salt creep will gradually reduce the size of the underground openings, and reexcavation of the openings will be required to maintain the minimum opening dimensions.

At the Deaf Smith site, the potential for roof instability is due to the interbeds that would exist above the underground openings. Rock falls can be prevented by adequate artificial support (regular rock bolting). As with the Davis Canyon and the Richton sites, significant maintenance may be required.

The in situ rock temperatures for each of the three sites are as follows: 34-43°C (93-109°F) for Davis Canyon, 27°C (81°F) for Deaf Smith, and 50°C (122°F) for Richton site.

The rock conditions assumed for the salt cost estimate include good tunnel stability, like those of the Davis Canyon and Richton sites, and favorable in situ rock temperatures similar to the Davis Canyon site. Reexcavation is assumed to be necessary to maintain the underground openings at all salt sites and was therefore assumed for the cost estimate. These parameters were selected to be representative of a generic salt site.

Ground-water conditions. At the Davis Canyon site, one minor aquifer is present above the host rock. The small amounts of ground water (28 gallons per minute) that would be encountered during shaft sinking can be readily handled with standard engineering practices. Little water is expected at the repository horizon.

At the Richton site, several regional aquifers are present above the host rock and adjacent to the flanks of the dome. Ground-water control during shaft sinking through the above-dome sediments and caprock would require ground freezing because of potentially high ground-water inflows (1,700 gallons per minute) and unconsolidated sediments above the salt dome. Little water is expected at the repository horizon the dome.

At the Deaf Smith site, there are aquifers between the host rock and the ground surface. The control of water while sinking shafts through these aquifers and water-bearing interbeds within the evaporite section can be accomplished with established technology. Potentially high ground-water inflows (1,400 gallons per minute) and unconsolidated sediments above the repository require pretreatment by freezing to allow shaft sinking through these sediments. Little water is expected within the repository horizon.

The salt cost estimate assumed that only small amounts of water would be encountered during shaft sinking (similar to Davis Canyon) and at the repository horizon (similar to all three salt sites). These conditions were assumed to be representative of a generic salt site.

Gassy conditions. Although there is no direct evidence that toxic gas is present at any of the three salt sites, experience is salt mines at other locations suggests the possibility. The hazards from such gas can be mitigated through safety procedures and adequate ventilation. These gassy conditions have been assumed in the generic salt cost estimate.

Subsurface conditions. Although specific salt sites may have certain subsurface conditions that are less favorable than others, on balance, it was assumed that mining will be conducted in a relatively good environment. This assumption was based on the subsurface conditions discussed above for the generic salt site.

Ventilation requirements. The ventilation requirements for salt can be described as moderate in comparison with basalt and tuff. Ventilation requirements are higher than those for tuff because of the deeper repository horizon and gassy conditions, but not as high as those for basalt.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The salt waste package consists of a thick-walled carbon-steel container and an internal canister assembly. The internal canister assembly segregates fuel rods into compartments for the consolidated spent-fuel design, whereas a spaceframe is used for the unconsolidated spent-fuel design. No external packing is assumed. The waste-packages assumed for the generic salt cost estimate are as follows:

Parameter	Unconsolidated spent fuel	Consolidated spent fuel
PWR/BWR ratio	1/2	12/30
Number of packages	4,600	12,200
Material	Carbon steel	Carbon steel

The total cost for the fabrication of all waste packages for a salt repository is $0.7 billion. This cost is lower than that for both tuff and basalt because salt repository emplaces significantly fewer waste packages than either tuff or basalt.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was assumed that about 22 million tons of salt will be excavated. This includes 4 million tons of salt reexcavated because of creep. The total amount excavated is higher than that assumed for basalt and tuff.

Mining method. The generic salt cost estimate assumed that a mechanized mining technique will be used to develop the underground facilities. Using this technique, mining is faster than mining by the conventional drill-and-blast technique, which is used for harder rocks like tuff and basalt.

Mining rate. The mining rate for salt can be characterized as "fast average." This rating is due to high mining productivity (tons per man-shift), which is the result of the following:

- The relative softness of the rock.
- The stability of the underground openings.
- Small quantities of water underground.
- Low temperatures.

The productivity for salt is 13.3 tons per man-shift. Salt has the highest productivity of all sites considered.

Underground-facility construction ease. The construction of the underground facilities will be easier at a repository located in salt than a repository located in basalt or tuff. This conclusion is based on the information previously presented which discussed the less difficult mining conditions associated with the salt repository.

Staffing levels and labor rates. Given the mining conditions expected at the generic salt site assumed for the cost estimate, staffing levels for the underground development can be estimated. The staffing levels (in full-time equivalents) for the emplacement period are as follows:

Surface	863
Underground	252
Total	1,115

These estimates are low when compared with other siting alternatives and result from the more favorable mining conditions expected at the salt sites.

Salt has the lowest labor rate ($28.50 per hour) of the sites considered. When combined with the low staffing levels assumed for salt, the labor cost for salt is expected to be low.

Underground facilities costs. Assuming the conditions described above, the total (construction, operation, and decommissioning) cost of the underground facilities for a salt repository is $2.2 billion. This is 26 percent of the total cost of $8.5 billion shown in Table 7-22. The remaining $6.3 billion consists of $1.8 billion for development and evaluation, $3.8 billion for surface facilities, and $0.7 for waste packages. The underground facilities cost for salt ($2.2 billion) is lower than that for the other sites.

Operation duration and backfilling. The life of a salt repository is 53 years long. It consists of a 27-year emplacement period, a 23-year caretaker period, and a 3-year backfill period. Because salt has the shortest backfill period of all the sites considered, salt also has the shortest operating life. The short operating phase, coupled with the low labor cost, results in low operating costs for salt.

Operating cost. The operating cost for a repository in salt is $4.9 billion. This is 58 percent of the total cost of $8.5 billion and is clearly the largest portion of the total-facility cost. The remaining $3.6 billion consists of $1.8 for development and evaluation, $1.6 billion for construction, and $0.2 billion for decommissioning.

Most of the operating costs are associated with the operation of the surface facilities. Of the $4.9 billion operating cost, $2.9 billion is for the operation of the surface facilities, $1.3 billion is for underground development, and $0.7 billion is for the fabrication of the waste packages.

Total facility costs. Table 7-23 presents the total facility costs for a generic salt repository. This table summarizes the costs mentioned in this section and is consistent with the costs shown in Table 7-22.

Table 7-23. Cost estimates for a salt repository
(billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D&E	1.8	0.0	0.0	0.0	1.8
Surface	--	0.8	2.9	0.1	3.8
Underground	--	0.8	1.3	0.1	2.2
Waste packages	--	0.0	0.7	0.0	0.7
Total	1.8	1.6	4.9	0.2	8.5

The total facility cost for salt is the same as for tuff and lower than that for basalt. This is due mainly to the lower underground costs resulting from favorable subsurface conditions.

Basalt repository

Host-rock depth. The interior of the Cohassett flow has been selected as the preferred candidate horizon for the basalt repository. The horizon is approximately 3,300 feet below the surface. It is the deepest horizon of all sites considered.

Rock conditions and tunnel stability. The basalt at the Hanford site is a physically and chemically stable rock that will be little affected by repository conditions. The rock is fractured. Heat-induced and rock-matrix fracturing are expected but will be minor and will not create a safety hazard.

High stress conditions are associated with basalt. This suggests that artificial support would be required for repository construction, operation, and closure. This artificial support is not considered minimal and will consist of rock bolts and shotcrete over wire mesh. This support is needed to control instabilities in the rock caused by stress. An example of a stress-induced instability is rock bursts. However, rock bursts are expected to be mild because of the low extraction ratio planned for the repository excavation and the closely jointed nature of the dense interiors. Rock bolts will use the high strength of basalt to control rock bursts or other deformations.

Basalt should not creep significantly, and therefore, maintenance of the underground openings will not be excessive.

The rock temperature in the Cohassett flow is high (51°C, or 124°F) and is a potential hazard to the health of the personnel working underground. A ventilation system that provides a continuous, acceptable working environment must be installed at the basalt repository. The effects of temperature are not expected to cause significant deterioration of support or instability of the rock.

Ground-water conditions. Aquifers are present between the Cohassett flow and the land surface. Ground-water inflow into the repository is high and is estimated to be about 100 gallons per minute. A worst-case estimate would be as high as 3,400 gallons per minute, but this is considered unlikely. The potential for these large water inflows can be reduced by drilling exploratory boreholes before excavation to identify any zones of abnormal water production.

During shaft sinking and the construction of the underground facility, ground-water will be controlled by established practices. After construction, seals associated with the shaft liner would protect the shafts and the repository drifts from ground-water inflow.

Because the rock temperature is high, it is expected that the water temperature will also be high. There is also the potential for water to enter the repository under high pressure.

Gassy conditions. Methane gas is not indigenous to basaltic rock. However, methane could occur in the underground openings because it might be introduced with any water inflow. A way to minimize the potential for methane entering the underground facilities is to control the water inflow into the repository. Ventilation will be required to control the concentration of any methane present underground. However, because of the limited amount of gas expected underground, gassy conditions were not assumed for the basalt cost estimate.

Subsurface conditions. Mining will be conducted in a difficult environment because of the conditions discussed above.

Ventilation requirements. The ventilation requirements for basalt are higher than those for salt and tuff because of the difficult subsurface conditions described above.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The basalt waste package consists of a thick-walled carbon steel container and an external packing assembly. An internal spaceframe is included for unconsolidated spent fuel. The external packing consists of a mixture of basalt and bentonite. The waste-package parameters assumed for the cost estimate are as follows:

Parameter	Unconsolidated spent fuel	Consolidated spent fuel
PWR/BWR ratio	4/9	4/9
Number of packages	1,000	38,800
Material	Carbon steel	Carbon steel

The total cost for the fabrication of all basalt waste packages is $1.1 billion. This cost is high because the basalt repository emplaces more waste-packages than any of the other sites.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was assumed that about 19 million tons of basalt will be excavated. This quantity is higher than that assumed for tuff, but lower than that assumed for salt.

Mining method. The basalt design assumed that the conventional drill-and-blast excavation technique will be used to develop the underground facilities. This technique is particularly suited to the subsurface conditions found at Hanford. For example, this technique is required because basaltic rock is very hard. However, the basalt mining method is slower than mechanized mining.

Mining rate. The mining rate for basalt can be characterized as "slow average." This rating is due to a low mining productivity (tons per man-shift), which is the result of the following:

- The hardness of basaltic rock.
- The depth of the repository horizon.
- The high stress conditions.
- The presence of large quantities of water underground.
- High temperatures.
- High excavation quantities.

The productivity for basalt is 3.1 tons per man-shift. This is the lowest productivity of all sites considered.

Underground facilities construction ease. The construction of the underground facilities will be more difficult for a repository located in basalt than a repository located in tuff or salt. This conclusion is based on the information previously presented which discussed the more difficult mining conditions associated with the deeper, higher temperature, saturated zones of the basalt repository.

Staffing levels and labor rates. Given the mining conditions expected at Hanford, staffing levels for the underground development can be estimated. These estimated staffing levels for the emplacement period are as follows:

Surface	917
Underground	1,051
Total	1,968

As shown above, the difficult mining conditions result in high staffing levels. When combined with a high labor rate ($31.00 per hour), the high staffing levels lead to high labor costs for basalt.

Underground-facility costs. Assuming the conditions described above, the total (construction, operation, and decommissioning) cost of the underground facilities of a basalt repository is $6.1 billion. This is just under 50 percent of the total cost of $12.3 billion shown in Table 7-22. The remaining $6.2 billion consists of $1.5 billion for development and evaluation, $3.6 billion for surface-facilities, and $1.1 billion for waste-packages. The cost of the underground facilities ($6.1 billion) is the highest of all sites considered.

Operating duration and backfilling. The basalt repository has a longer operating life than both tuff and salt: 61 years. It consists of a 27-year emplacement period, a 23-year caretaker period, and an 11-year backfill period. This is the longest operating phase of all sites considered because basalt assumed the longest backfill period. The long operating life, coupled with the high staffing levels and high labor rates, leads to high operating costs for basalt.

Operating cost. The operating cost for a basalt repository at the Hanford site is $8.3 billion. This is 67 percent of the total cost of $12.3 billion and is clearly the largest partion of the total facility cost. The remaining $4.0 billion consists of $1.5 billion for development and evaluation, $2.3 billion for construction, and $0.2 billion for decommissioning.

Most of the operating costs are associated with underground development. Of the $8.3 billion, $4.3 billion is for underground development, $2.9 billion is the operation of the surface facilities, and $1.1 billion is for the waste packages.

Total facility costs. Table 7-24 presents the total-facility costs for the basalt repository. This table summarizes the costs mentioned in this section; the costs are consistent with the costs shown in Table 7-22.

Table 7-24. Cost estimates for a basalt repository (billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D&E	1.5	0.0	0.0	0.0	1.5
Surface	---	0.5	2.9	0.2	3.6
Underground	---	1.8	4.3	0.0	6.1
Waste packages	---	0.0	1.1	0.0	1.1
Total	1.5	2.3	8.3	0.2	12.3

The total facility cost for basalt is the highest of all sites considered. This is due primarily to the higher underground costs resulting from the difficult subsurface conditions.

Tuff repository

Host rock depth. The proposed repository horizon is about 1,200 feet deep. This is the most shallow horizon of all sites considered.

Rock conditions and tunnel stability. The welded tuff of the Toppah Spring Member at Yucca Mountain is a physically and chemically stable rock that will be little affected by repository conditions. Currently, the rock is fractured, and any additional thermally induced fracturing will be minor.

The rock strength of welded tuff and the associated in situ stresses are favorable. The fractured nature of the tuff, however, may provide the potential for rock falls in underground openings. Faults encountered in the underground facility may also contribute to local instabilities because of the poor quality of rock associated with the fault zones. The potential for rock falls can be mitigated through the use of appropriate artificial supports for the underground openings. Previous excavation experience at the Nevada Test Site indicates that the expected artificial support requirements at Yucca Mountain are regularly spaced rock bolts, with steel mesh covering the rock surface for safety. Occasional supplemental bolting or shotcrete may be required in local areas of poor-quality rock. These requirements are considered minimal.

Little deterioration of the rock and the artificial support is expected over time and from temperature changes, since the tuff does not creep. Therefore, the rock is expected to remain in a stable condition and will not require extensive maintenance for the underground openings.

The rock temperature is favorable (27°C or 81°F) and is not expected to be a hazard to the health of the personnel working underground. The effects of temperature are not expected to significantly affect the stability of the mined openings.

Ground-water conditions. At the Yucca Mountain site, there are no aquifers between the host rock and the land surface. Because the repository would be located above the water table, no significant amounts of ground water are likely to be encountered in the shafts or the underground workings.

Gassy conditions. No significant accumulations of toxic gases are expected at the repository horizon. Therefore, gassy conditions have not been assumed for the tuff cost estimate.

Subsurface conditions. Mining will be conducted in a relatively good environment, assuming the conditions discussed above.

Ventilation requirements. The ventilation requirements for tuff are lower than those for basalt and salt. This is a result of the relatively good environment expected underground.

Waste-package costs. The design for the waste package is determined by subsurface conditions. The tuff waste package consists of a stainless-steel canister and an internal spaceframe. No external packing is assumed. The waste-package parameters assumed for the cost estimate are as follows.

Parameter	Unconsolidated spent fuel	Consolidated spent fuel
PWR/BWR ratio	3/9	6/18
Number of packages	1,400	23,100
Material	Stainless steel	Stainless steel

The total cost of fabricating all tuff waste packages is $1.1 billion. This cost is high because of the combined effect of emplacing a large number of waste packages and high material costs. The cost of the tuff waste package is higher than the cost of the salt waste package for this reason. However, the tuff waste package costs the same as the basalt waste package. This happens because, though tuff emplaces a smaller number of packages than basalt, the resulting cost savings are offset by the cost of the stainless-steel container, which is higher than the cost of the carbon-steel container for basalt.

Excavation quantities. Given the waste-package requirements, the excavation requirements can be calculated. For the cost estimates used here, it was estimated that about 17 million tons of tuff will be excavated. This is lower than that assumed for salt and basalt.

Mining method. The tuff design assumed that mechanized mining techniques will be used in conjunction with conventional techniques to develop the underground facilities. This should lead to a mining rate that is faster than that basalt (conventional mining only) but not as fast as that for salt (mechanized mining only).

Mining rate. The mining rate for tuff can be characterized as "fast average." This rating is due to a high mining productivity (tons per man-shift), which is the result of the following:

- Shallow repository horizon.
- The stability of underground openings.
- Lack of water underground.
- Lower temperatures.
- Lower excavation quantities.

The productivity for tuff is 9.1 tons per man-shift. The productivity for basalt is significantly lower because of the more difficult mining conditions that will be encountered. The productivity for salt is higher largely because salt is softer than tuff and therefore can use only totally mechanized mining techniques.

Underground facilities construction ease. The construction of the underground facilities will be easier at a repository located in tuff than a repository located in basalt, but not salt. This conclusion is based on the information previously presented which discussed the mining conditions associated with the tuff repository.

Staffing levels and labor rates. Given the mining conditions expected at the tuff site, staffing levels for the underground development can be estimated. The staffing levels for the emplacement period (in full-time equivalents) are estimated to be as follows:

Surface	846
Underground	372
Total	1,218

The staffing estimates can be characterized as low, but not the lowest of all sites considered. Tuff has the highest labor rate ($32.00 per hour) of the sites considered. However, when combined with the staffing levels assumed for tuff, the labor cost is expected to be low and fall between the labor cost expected as basalt (high) and salt (low).

Underground facility costs. Assuming the conditions described above, the total (construction, operation, decommissioning) costs of the underground facilities for a tuff repository is $2.3 billion. This is 27 percent of the total cost of $8.5 billion shown in Table 7-22. The remaining $6.2 billion consists of $1.5 billion for development and evaluation, $3.6 billion for surface facilities, and $1.1 for waste packages.

Operation duration and backfilling. The tuff repository will be in operation for 58 years. This consists of a 27-year emplacement period, a 23-caretaker period, and an 8-year backfill period. The 58-year operating phase is 3 years shorter than the basalt operating period and 5 years longer than the salt operating period. This is due to the duration of the backfill period assumed for each host rock. Because of the operating period, tuff has moderate operating costs when compared with salt and basalt.

Operating costs. The operating cost for a repository located at the Yucca Mountain site is $5.8 billion. This is 68 percent of the total cost of $8.5 billion and is clearly the largest portion of the total facility cost. The remaining $2.7 billion consists of $1.5 billion for development and evaluation, $1.1 billion for construction, and $0.1 for decommissioning.

Most of the operating costs are associated with the operation of the surface facilities. Of the $5.8 billion total operating cost, $2.8 billion is for the operation of the surface facilities, $1.9 billion is for underground development, and $1.1 billion is for the waste packages.

Total facility costs. Table 7-25 presents the total facility costs for a tuff repository. This table summarizes the costs mentioned in this section and is consistent with the costs shown in Table 7-22.

Table 7-25. Cost estimates for a tuff repository (billions of 1984 dollars)

Cost category	D&E	Construction	Operation	Decommissioning	Total
D & E	1.5	0.0	0.0	0.0	1.5
Surface	---	0.7	2.8	0.1	3.6
Underground	---	0.4	1.9	0.0	2.3
Waste packages	---	0.0	1.1	0.0	1.1
Total	1.5	1.1	5.8	0.1	8.5

The total-facility cost for tuff is the same as that salt and lower than that for basalt. This is due mainly to the lower underground costs that result from favorable subsurface conditions.

GLOSSARY AND LIST OF ACRONYMS AND ABBREVIATIONS

GLOSSARY

ablation	All processes by which snow and ice are lost from a glacier; also, the amount lost.
absorbed radiation	A measure of the amount of ionizing radiation deposited in a given mass of absorbing medium. The unit of absorbed radiation is the rad.
access corridor	Access to controlled roads, railroads, transmission for utilities, or other means.
accessible environment	The atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that are outside the controlled area.
Act	The Nuclear Waste Policy Act of 1982.
actinides	Chemical elements with atomic numbers beginning at 89 and continuing through 103.
active fault	A fault along which there is recurrent movement, which is usually indicated by small periodic displacements or seismic activity.
active dissolution front	See "dissolution front."
active institutional controls	Controls instituted by government to guard a repository against intrusion and to perform monitoring or maintenance operations.
adit	A nearly horizontal passage from the surface by which a mine is entered.
adsorption	Adherence of ions or molecules that are in solution to the surface of solids with which they are in contact.
aeromagnetic survey	A survey made of the magnetic field of the earth by the use of electronic magnetometers suspended from an aircraft.
affected area	Either the area of socioeconomic impact or the area of environmental impact.
affected Indian Tribe	Any Indian Tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility: provided that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the Tribe, that such effects are both substantial and adverse to the Tribe.

affected State	Any State that (1) has been notified by the DOE in accordance with Section 116(a) of the Act as containing a potentially acceptable site; (2) contains a candidate site for site characterization or repository development; or (3) contains a site selected for repository development.
aging	Storage of radioactive materials, especially spent nuclear fuel, to permit the decay of short-lived radionuclides.
air change	The rate of change of ventilation air, usually in terms of air changes per hour.
albite	A white or colorless triclinic mineral of the feldspar group ($NaAlSi_3O_8$). It occurs commonly in igneous and metamorphic rocks.
alkaline	Having a pH greater than 7.
alluvial fan	An outspread, gently sloping mass of alluvium deposited by a stream.
alluvial piedmont	Alluvium that lies at the base of a mountain or a mountain range.
alluvial plain	A level of gently sloping surface adjacent to a stream, developed over time by the periodic flooding of, and associated deposition by, the stream (either existing today or active in the past).
alluvium	A general term for clay, silt, sand, gravel, or similar material that is not compacted and has been deposited in fairly recent geologic time by streams, rivers, or floods.
alpha decay	A radioactive transformation in which an alpha particle is emitted by a nuclide, thus changing one nuclide to another that has a smaller atomic number and weight.
alpha particle	A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation--alpha, beta, and gamma.
amorphous silica	A form of silica that lacks any ordered internal structure.
amphibole	A mineral group that includes common rock-forming minerals characterized by good prismatic cleavage.
angle of internal friction	The angle between a resultant force and the line perpendicular to the plane of friction.
anhydrite	A white to grayish or reddish mineral of anhydrous calcium sulfate, $CaSO_4$.

anoxic	A general term meaning in the absence of oxygen.
anticline	An uparched fold composed of strata that dip outward from a common ridge or axis. The core of an anticline contains stratigraphically older rocks and is convex upward.
anticlinorium	A series of anticlines and synclines so arranged structurally that together they form a general arch, or anticline.
antithetic fault	A fault that dips in the opposite direction from the direction in which the associated sediments dip. Opposite of synthetic fault.
aphanitic	Applied to a texture of rocks, the mineral constituents of which are so fine that the individual crystals or grains cannot be distinguished by the unaided eye.
aphyric	An igneous rock texture showing two generations of the same mineral but without large crystals.
application	The act of making a finding of compliance or noncompliance with the qualifying or disqualifying conditions specified in the siting guidelines, in accordance with the types of findings specified in Appendix III of the siting guidelines.
aquiclude	A geologic formation that will not transmit water fast enough to furnish an appreciable supply.
aquifer	A formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield sufficient quantities of water to wells and springs.
aquitard	A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not yield water to wells or springs, but may serve as a storage unit for ground water. (See also "aquiclude.")
argillaceous	A term applied to all rocks or substances composed of clay minerals or having a notable portion of clay in their composition; examples are shale and slate.
argillite	A compact rock, derived from either mudstone or shale, that has undergone a somewhat higher degree of induration than is present in mudstone or shale.
artesian	A term describing ground water confined under hydrostatic pressure. The water level in a artesian well stands above the top of the artesian water body it taps. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well.

atmospheric dispersion — Atmospheric transport of particulates or gases by airflow within the atmosphere and atmospheric diffusion by random air motions.

atmospheric stability class — An index that indicates the atmosphere's ability to disperse airborne releases.

atomic energy defense activity — Any activity of the Secretary of Energy performed in whole or in part in carrying out any of the following functions: naval reactor development, weapons activities, verification and control technology, defense nuclear materials production, defense nuclear waste and materials by-products management, defense nuclear materials security and safeguards and security investigations, and defense research and development.

augite — A common mineral of the clinopyroxene group. It is usually black, greenish black, or dark green, and occurs as an essential constituent in many basic igneous rocks and in certain metamorphic rocks.

backfill, backfilling — The placement of materials, originally removed or new, into the excavated areas of a mine, including waste-emplacement holes, drifts, accessways, and shafts.

background radiation — Radiation that is produced by sources such as naturally occurring radioactive minerals in the earth, cosmic rays, and naturally occurring radionuclides in living organisms.

barrier — Any material or structure that prevents or substantially delays the movement of water or radionuclides.

basalt — A dark to medium dark igneous rock usually formed from lava flows and composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained ground mass.

basalt flow — A solidified body of lava formed from the outpouring of molten basalt from a fissure or vent. (See "intraflow structures.")

base metal — Any of the more common or more chemically active metals (e.g., lead and copper).

basement rock — Undifferentiated rocks that underly the stratified rocks of interest in an area.

basin — A depressed area in the earth's surface with no outlet. Sediments may have accumulated in such areas.

Basin and Range province — Physiographic province in the SW U.S. characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad, intervening basins.

bedding — The arrangement of rock in layers of varying thickness and character.

bedrock — Solid rock that underlies all soil, sand, clay, gravel, and loose material on the earth's surface.

benchmarking of computer codes — Code-to-code comparisons in which simulations obtained with DOE codes are compared to those obtained with other available codes of the same kind. The test cases used for benchmarking will use data representative of the actual repository setting. Benchmarking is complete when a reasonable consensus between independent code predictions is achieved.

bench-scale — As related to testing, a type of laboratory or, occasionally, field test; refers to the size of tests being performed. Bench-scale tests are run to determine the practicability of incorporating an observed phenomenon into a design or test procedure.

bentonite — A clay, containing the mineral montmorillonite, that was formed over time by the alteration of volcanic ash and has variable magnesium and iron contents. Bentonite can absorb large quantities of water and expand to several times its normal volume.

beta particle — A negatively charged particle, physically identical with the electron, that is emitted by certain radionuclides.

biological half-life — The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled.

biosphere transport (biotransport) — The movement of radionuclides through food chains. Used in contrast to geotransport.

biotite — A common rock-forming mineral of the mica group. It is black in hand specimen and brown or green in thin section, and it has perfect basal cleavage.

bioturbation — The churning and stirring of a sediment by organisms.

blind-hole drilling — A technique for sinking shafts. It uses a multiple-cone bit with a diameter larger than 6 feet.

block faulting — A type of vertical faulting in which the crust is divided into structural or fault blocks of different elevations and orientations.

blooie line — A pipe or flexible tube that conducts air or other gas laden with cuttings from the collar of a borehole to a point far enough removed from the drill rig to keep air around the drill dust-free.

boiling-water reactor	A nuclear reactor that uses boiling water to generate electricity.
boomtown	A community that experiences a sudden rapid growth and expansion.
borehole	An excavation, formed by drilling or digging, that is essentially cylindrical and is used for exploratory purposes.
borehole jacking test	A test that measures in situ rock-mass deformation through the application of unidirectional pressures to the opposite sides of a borehole.
borehole log	A record of the characteristics and thickness of the different layers of rock or other material encountered in the excavation of a borehole.
borosilicate glass	A silicate glass containing at least 5 percent boric acid and used to solidify commercial or defense high-level waste.
branch corridor	A corridor that runs at an angle to the main corridors of the repository and that leads to the storage rooms.
brattice	A temporary fabric curtain from directing or restricting underground ventilation flow.
breccia	Rock consisting of sharp fragments cemented together or embedded in a fine-grained matrix.
bridge plug	A downhole tool, composed primarily of slips, plug mandrell, and rubber sealing elements that is run in and set in dense, nonfractured rock in a borehole to isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones.
brine	Highly saline water containing calcium (Ca), sodium (Na), potassium (K), and chlorine (Cl) and minor amounts of other elements.
brine migration	The movement of brine through interstices in rock.
broadband sound	Sound that encompasses the audible frequencies.
bulkhead	A stone, steel, wood, or concrete wall-like structure designed to resist earth or water pressure.
cage	The car or platform of a mine hoist used to carry men or materials.
calcine	Material heated to a temperature below its melting point to bring about loss of moisture and oxidation.

calcite — A common rock-forming mineral ($CaCO_3$) that is usually white or gray. It is the chief constituent of limestone and most marble.

caldera — A large basin-shaped volcanic depression, more or less circular.

Cambrian — The oldest of the periods of the Paleozoic Era, which lasted from 570 million to 500 million years ago.

candidate horizon — The Cohassett flow.

candidate site — An area, within a geohydrologic setting, that is recommended by the Secretary of Energy under Section 112 of the Act for site characterization, approved by the President under Section 112 of the Act for characterization, or undergoing site characterization under Section 113 of the Act.

canister — A metal vessel for consolidated spent fuel or solidified high-level waste. Before emplacement in the repository, the canister will be encapsulated in a disposal container.

capable fault — A fault that has exhibited one or more of the following characteristics, as described in the NRC's 10 CFR Part 50: (a) movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years, (b) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault, or (c) a structural relationship to a capable fault according to characteristics a and b such that movement on one could be reasonably expected to be accompanied by movement on the other.

capillary fringe — The zone immediately above the water table in which all or some of the rock pores or fractures are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.

caprock — Layers of insoluble mineral deposits that may be derived from the dissolution of a salt dome, "capping" the dome.

carnallite — A white, brownish, or reddish mineral, $KCl \cdot MgCl_2 \cdot 6H_2O$.

carbonate — A mineral compound characterized by a fundamental anionic structure of CO_3^{+2}. Calcite ($CaCO_3$) is an example of a carbonate.

casing — (1) A liner in a shaft or borehole to prevent entry of loose rock, gas, or liquid, or to prevent the loss of circulating liquid into porous, cavernous, or fractured ground. (2) The process of inserting casing into a borehole.

cask	See "shipping cask" and "transfer cask."
catchment area	As applied to an aquifer, the recharge area and all areas that contribute to it.
Cenozoic	The latest of the eras into which geologic time, as recorded by the stratified rocks of the earth's crust, is divided; this era is considered to have begun about 65 million years ago.
chilled contact	That part of a mass of igneous rock, near its contact with older rocks, that is finer grained than the rest of the mass, because of its having cooled more rapidly.
chilled zone	The border or marginal area of an igneous intrusion, characterized by a finer grain than the interior of the rock mass due to more rapid cooling.
chronic intake	A continuous inhalation or ingestion exposure lasting for days or years.
cladding	A long metal tube used to contain pellets of nuclear fuel; usually made of stainless steel or Zircaloy, an alloy of steel and zirconium.
cladding hulls	The empty metal casings that remain after spent fuel is removed from them for processing.
clastic dike	A tabular body of clastic material transecting the bedding of a sedimentary formation, representing extraneous material that has invaded the containing formation along a crack.
clastic rock	Any deposit that is composed of fragments of preexisting rocks or of solid products formed during the chemical weathering of such older rocks and has been transported some distance from the place of its origin.
clay	A fine-grained natural material composed mainly of hydrous aluminum silicates. It may be a mixture of clay minerals and small amounts of nonclay materials, or it may be predominantly one clay mineral. The type of clay is determined by the predominant clay mineral (i.e., kaolin, montmorillonite, illite, halloysite, etc.).
closure	Final backfilling of the remaining open operational areas of the underground repository facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.
coefficient of friction	An experimental constant dealing with forces when two solid bodies that are in contact slide or tend to slide on each other. The constant depends largely on the roughness of the mating surfaces.

coeval — Originating or existing over the same period of time.

cohesion — Shear strength of a rock not related to interparticle friction.

collapse fracture — Any rock structure resulting from the removal of support and consequent collapse by the force of gravity.

collar — The top or uppermost portion of a shaft. A concrete ring or slab around a shaft used to prevent water inflow and to support the headframe.

colloid — A suspension of finely divided particles in a liquid, gaseous, or solid substance. Suspended particles are not easily filtered out.

colluvium — A general term applied to the accumulation of loose incoherent soil and rock material at the base of a slope.

colonnade — In columnar jointing, the lower portion of a basalt flow that structurally has thicker and better formed columns than the upper portion (or entablature). The colonnade may also occur in the upper third of a flow (directly below the flow top).

Columbia Plateau — A region of approximately 200,000 square kilometers (78,000 square miles) occupying a major part of eastern Washington, a portion of northeastern Oregon, and a small part of western Idaho. It is underlain by a flood basalt province consisting of approximately 375,000 cubic kilometers (90,000 cubic miles) of basalt; this is called the Columbia River Basalt Group.

columnar fan — A variation of the internal structure of a basalt flow in which the orientation of the columnar joints changes from generally parallel to make a fanlike, or radial, pattern.

columnar jointing — Jointing that breaks the rock into columns. The joints usually form a fairly well-defined prism that is hexagonal in cross section. In basaltic flows they result from contraction during the cooling of the igneous mass in which they occur.

commercial waste — Radioactive waste generated in private industrial and other nongovernment facilities--in particular, the spent fuel discharged from nuclear power reactors and the waste resulting from the reprocessing of spent fuel.

complex — In chemistry, any combination of cations with molecules or anions containing free pairs of electrons. An organic complex is a complex in which the cation is combined with an organic ligand. An inorganic complex is formed when the cation is combined with an inorganic ligand.

compressive strength — The maximum compressive stress that can be applied to a material under given conditions before failure occurs.

conceptual model — A physical description of a system devised to show property variations as based on field and laboratory measurements and best technical judgments.

concreting — In tunneling, a method of support in which tunnel surfaces are coated with concrete and sometimes containing reinforcing bar patterns. (See also "shotcrete.")

confined aquifer — An underground water-bearing unit or formation with defined, relatively impermeable upper and lower boundaries. It contains confined ground water whose pressure is usually greater than atmospheric pressure throughout.

confinement — As pertains to radioactivity, the confinement of radioactive material within some specified bounds; confinement differs from containment in that there is no absolute physical barrier.

confining unit — A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

conglomerate — A cemented clastic rock containing rounded or dissimilar fragments of gravel or pebble size.

constitutive model — A mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations that mathematically express the relationship between the quantities of interest (e.g., constitutive equations establishing a linear elastic relationship between stress and strain).

contact-handled transuranic waste — Transuranic waste, usually contained in metal drums, whose surface-radiation-dose rate (less than 0.2 rem per hour) is sufficiently low to permit direct handling. Such waste does not usually require shielding other than that provided by its container.

containment — The confinement of radioactive waste within a designated boundary.

container — The metal envelope in the waste package that provides the primary containment function of the waste package and is designed to meet the containment requirements of 10 CFR Part 60.

containerized waste — Container and contents, including the waste and any liner or stabilizing material.

contamination — The presence of radioactive material on the outside surfaces of a transportation vehicle, a shipping cask, repository equipment, or a waste disposal container.

continuous mining machine — A machine equipped with a rotating cutting head with picklike bits for cutting into rock and for dropping the cuttings into a collection device for loading into cars or conveyors.

controlled area — A surface location, to be marked by suitable monuments, extending horizontally no more than 5 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be prohibited before and after permanent closure.

conventional shaft-sinking methods — Methods employing drilling, blasting, and mucking procedures in shaft construction.

cooling (spent fuel) — Storage of fuel elements after discharge from reactors, usually under water, to allow for the decay of short-lived radionuclides and hence the decrease of radioactivity and heat emission to acceptable levels. Synonymous with aging.

cooling joints — A joint that is formed as a result of contraction during the cooling of a basalt flow. (See "joint.")

core (geologic) — A cylindrical section of rock, usually 5 to 10 centimeters in diameter and up to several meters in length, taken as a sample of the interval penetrated by the drill.

core disking — A phenomenon occurring in the drilling of highly stressed hard rock, which may result in the formation of disks or wafers of relatively uniform thickness with curved surfaces developed approximately normal to the axis of the core.

core drill — A mechanism designed to rotate and cause an annular rock-cutting bit to penetrate rock formations, producing cylindrical cores of the formations penetrated.

coulee — A dry or intermittent stream valley of considerable extent. On the Columbia Plateau coulees are a long, steep-walled, trenchlike gorge or valley that commonly is an abandoned overflow channel that temporarily carried meltwater from an ice sheet.

craton — A generally large part of the earth's crust that has attained stability and is relatively immobile.

creep — Slow deformation (alteration of form) that results from long application of a stress.

creep closure	Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.
crib	As used in underground mining for roof support, a structure composed of frames of timber laid horizon- tally on one another or of timbers built up as in the walls of a log cabin.
cristobalite	A mineral, SiO_2, that is a high-temperature form of quartz and tridymite, and occurs as white octahedrons in acidic volcanic rocks.
critical path	Environmental exposure pathway that dominates the transport of material, from the source of emission to human receptors.
criticality	The condition of supporting a nuclear chain reaction. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle.
crosscut	(1) A small passageway driven at right angles to the main entry to connect it with a parallel entry or air course. (2) A level driven across the course of a vein or across the general direction of the workings.
cryptocrystalline	A texture of rock consisting of crystals that are too small to be recognized and distinguished under an ordinary microscope.
crystalline	Of or pertaining to the nature of a crystal (i.e., having a regular molecular structure).
crystalline rock	An inexact but convenient term designating igneous or metamorphic rock, as opposed to sedimentary rock.
cumulative impact	Projected impact of a proposed facility in combination with other existing and proposed facilities and actions.
cumulative releases of radionuclides	The total number of curies of radioactivity entering the accessible environment in any 10,000-year period, normalized on the basis of radiotoxicity in accordance with 40 CFR Part 191. The peak cumulative release of radionuclides refers to the 10,000-year period during which any such release attains its maximum predicted value.
curie	A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second.

damaged rock zone — A zone of rock surrounding any underground opening in the controlled area of repository that has lost structural integrity from the construction or operation of the repository, with the result that the performance of the affected area has a significant adverse effect on long-term waste isolation. The sources of damage include, but are not limited to, the strains within the rock mass that arise from the redistribution of naturally occurring stresses or excavation-induced stresses.

Darcian flow — Flow of fluids that is described by a numerical formulation of Darcy's law.

darcy — A unit of measurement of permeability equivalent to the passage of 1 cubic centimeter of fluid, flowing in 1 second under 1 atmosphere of pressure through a porous medium with a cross-sectional area of 1 square centimeter and a length of 1 centimeter.

dBA — A sound level in decibels measured with the A-weighting network of a sound-level meter. The A-weighting network adjusts the measurement to correspond with the frequency response of the human ear.

debris flow (geologic) — A moving mass of rock fragments, soil, and mud, with more than half the particles being larger than sand size.

decay, radioactive — (1) The process whereby radioactive materials undergo a change from one isotope, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide.

decay chain — The sequence of radioactive disintegrations in succession from one nuclide to another until a stable daughter product is reached.

decibel — A unit of measure, on a logarithmic scale, of the ratio of particular sound pressure to a standard reference pressure squared. The reference pressure is 20 micropascals.

decollement — Detachment structure of strata due to deformation, resulting in independent styles of deformation in the rocks above and below.

decommissioning — The permanent removal from service of surface facilities and components necessary only for preclosure operations, after repository closure, in accordance with regulatory requirements and environmental policies.

decontamination — The removal of unwanted material (especially radioactive material) from the surface of, or from within, another material.

decrepitation — The shattering of a rock mass or rock sample caused by the buildup of excessive pressures in contained fluids as a result of heating, or the action of differential thermal expansion or contraction of its heated grains.

defense waste — Radioactive waste derived from the manufacturing of nuclear weapons and the operation of naval reactors.

Delphi method — A structured process for eliciting expert opinion and for consensus forming. The process is distinguished by anonymity of response of individual participants.

dense interior — See "flow interior."

density log — A gamma-gamma log used to indicate the varying bulk densities of rocks penetrated in drilling by recording the amount of back-scattering of gamma rays.

denudation — The sum of the processes that result in the wearing away or the progressive lowering of the earth's surface by various natural agents, including weather, erosion, mass wasting, and transportation.

deposition — The laying down of rock-forming material by any natural agent (e.g., the mechanical settling of sediment from suspension in water).

design bases — Information that establishes boundaries for design by specifying the functions to be performed by the structure, system, or component of a facility and the values or ranges of values for controlling parameters.

design-basis event — A credible accident or natural phenomenon (e.g., earthquakes or flood) that is used to establish design bases because its consequences are the most severe of all those postulated for other credible accidents or phenomena.

design life — The period of time for which a structure, system, or component is designed to perform its intended function. The design life of the repository ends when the repository is of no further operational use, waste retrieval is no longer a concern, and closure and decommissioning begin.

detritus — Loose rock or mineral material removed directly by mechanical means or deposited at another site.

deviatoric stress — In the engineering discipline of rock mechanics, the difference between the major principal stress and the minor principal stress.

devitrification — The process by which glassy substances lose their vitreous nature and become crystalline.

dextral shear — In tectonics, a shear in which the portion on the far side appears to be offset to the right. (See also "right-lateral offset".)

diagenesis — All the changes undergone by a sediment after its initial deposition, exclusive of weathering and metamorphism, or the recombination or rearrangement of a mineral into a new mineral. Also known as diagenetic alteration.

diapir — A geologic flow structure, either a dome or an anticline, in which overlying rocks have been ruptured by the flow upward of a plastic core material such as salt.

diapirism — The process by which a diapir is produced.

diastrophism — A general term for all movement of the crust produced by earth forces, including the formation of continents and ocean basins, plateaus and mountains, folds of strata, and faults.

diatomaceous earth — A fossil accumulation of diatoms, usually with some radiolaria and smaller amounts of foraminifera.

diffusion — A solute-spreading phenomenon important only at low ground-water velocities.

dike (geologic) — A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.

diktytaxitic — A rock texture characterized by numerous jagged, irregular vesicles bounded by crystals, some of which protrude into the cavities.

dip — The angle at which a bed, stratum, vein, or any planar feature of rock is inclined from the horizontal. The dip is measured perpendicular to the strike of the planar feature. (See "strike.")

dip-slip fault — A fault in which the earth's displacement is parallel to the dip of the fault, and there is no horizontal component of movement parallel to the strike.

direct work force — People hired for jobs at the repository.

Dirichlet boundary conditions — This phrase means that the value of the mathematical function is assigned definite values at the boundary.

discharge point (or area) — In ground-water hydraulics, the point (or area) where water comes out of an aquifer onto the surface.

discontinuity (seismologic)	A surface at which seismic-wave velocities abruptly change; a boundary between the seismic layers of the earth.
dispersion	The solute-spreading or dilution phenomena caused by mechanical mixing during ground-water movement and molecular diffusion.
disposal	The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the isolation of such waste from the accessible environment.
disposal system	See "repository system."
disqualifying condition	A condition that, if present at a site, would eliminate that site from further consideration.
disruptive event	Any action that could breach a barrier.
dissolution	A process of chemical weathering by which minerals and rocks are dissolved in water.
dissolution front	An underground zone in which rocks or minerals are being dissolved in a fluid (more specifically, in ground water).
distribution coefficient (K_d)	The ratio of the concentration of a solute sorbed by ion-exchange substances (e.g., earth materials, particularly clays) to the concentration of the solute remaining in solution. A large distribution coefficient implies that the substance is readily sorbed and is redissolved slowly. The concentration of a material in the solid phase (i.e., rock or sediment) (moles per gram) divided by the concentration of material in the aqueous phase (moles per liter).
disturbed zone	That portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of a geologic repository.
dolomite	A sedimentary rock consisting mostly of the mineral magnesium calcium carbonate, $CaMg(CO_3)_2$. It is commonly found with, and is usually formed from, limestone.
dome (general)	A dome-shaped landform or rock mass; a large igneous intrusion whose surface is convex upward with sides sloping away at low but gradually increasing angles; an uplift or an anticlinal structure, either circular or elliptical, in which the rock dips gently away in all directions.

dome (salt) — A diapiric or piercement structure with a central plug that has risen through the enclosing sediments from a deep mother bed of salt.

dose commitment — The integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of the intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment.

dose equivalent (radiation) — A concept used to describe the effectiveness of a given unit of absorbed radiation dose. The unit of dose equivalent is the rem.

dose limit — The limit established by the Environmental Protection Agency or the Nuclear Regulatory Commission for the exposure of people to radiation.

dose rate — The radiation dose received per unit of time.

dosimetry — The measurement and evaluation of absorbed radiation dose or dose equivalent.

downfaulted — Rocks on the downthrown side of a fault.

downgradient — Movement of ground water from an area of higher hydraulic pressure to one of lower pressure.

downwarping — Subsidence of the earth's crust.

drag fold — A minor fold, usually one of a series, formed in an incompetent bed lying between more-competent beds, produced by movement of the competent beds in opposite directions relative to one another.

drift — In mining, a horizontal opening excavated underground. In geology, a general term for all rock material transported either by a glacier or by proglacial meltwater.

drill-and-blast mining — A method of mining in which small-diameter holes (less than 1 foot) are drilled into the rock and then loaded with explosives. The blast from the explosives breaks the rock from the face of a structure so that rock can be removed. The underground opening is expanded by repeated drilling and blasting.

drill and test — Hydrologic testing of selected rock intervals when each interval is first penetrated by a borehole. This testing takes place before a borehole is completed to its total depth.

drill hole	A cylindrical hole made by drilling, especially one made by cable tool rigs or one made to explore for valuable minerals or to obtain geologic information. Synonymous with borehole.
drill-stem test	A test of the productive capacity of a well when it is still full of drilling mud.
ductility	A property of a solid material that undergoes more or less plastic deformation before it ruptures.
earthquake	A sudden motion or trembling in the earth caused by the release of slowly accumulated strain.
earthquake swarm	A series of minor earthquakes, none of which may be identified as the main shock, occurring in a limited area and time.
ecosystem	An ecologic system composed of organisms and their environment.
ecotone	An ecological community of mixed vegetation formed by the overlapping of adjoining ecologic communities.
eddy bar	An accumulation of sand and gravel in an eddying current marginal to a main catastrophic flood channel.
effective porosity	The amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.
Eh	The oxidation potential of a solution.
elastic modulus (modulus of elasticity)	A constant expressing the ratio of the unit stress or strain to the unit deformation of a material when a stress or strain is exerted on the material.
electrical resistivity	The electrical resistance per unit length of a unit cross-sectional area of a material.
emplacement	The act of emplacing radioactive waste, encapsulated in disposal containers, into a prepared hole.
employment multiplier	A figure based on the estimated ratio of the sum of indirect and direct project employment to direct project employment. It is multiplied by the expected project employment to give total direct and indirect employment.
endangered species	Any plant or animal species protected under Public Law 93-205 that is in danger of extinction throughout all or a significant portion of its range (other than species of insects determined to be pests).

engineered-barrier system	The manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. It includes the radioactive waste form, radioactive-waste containers, material placed over and around such containers, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.
entablature	The upper to the middle portion of a basalt flow that has thinner and less regular columns than the lower portion or colonnade.
environmental assessment	The document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982.
environmental impact statement	The document required by Section 114 of the Nuclear Waste Policy Act of 1982.
eolian	Pertaining to the wind; especially said of sediment deposition by the wind, of structures like wind-formed ripple marks, or of erosion accomplished by the wind.
ephemeral drainage	A stream or portion of a stream that flows briefly in direct response to precipitation in the immediate vicinity and is dry during some or most of the year. Its channel is at all times above the water table.
epicenter (of an earthquake)	The point on the earth's surface directly above the exact subsurface location of an earthquake.
erg	A unit of energy or work equal to the work done by a force of 1 dyne acting over a distance of 1 centimeter.
erosion	The wearing-away of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, wind, and underground water.
escarpment	A long, more or less continuous cliff or relatively steep slope that was produced by erosion or faulting and faces in one general direction, breaking the continuity of the land by separating two level or gently sloping surfaces.
eustatic	Pertaining to world wide changes of sea level that affect all the oceans. (See also "glacio-eustatic.")
evaluation	The act of carefully examining the characteristics of a site in relation to the requirements of the qualifying or disqualifying conditions specified in the siting guidelines. Evaluation includes the consideration of favorable and potentially adverse conditions.

evaporite — A sedimentary rock composed primarily of minerals from a solution that became concentrated by evaporation, especially salts deposited from a restricted or enclosed body of seawater or from the water of a salt lake.

excavation support ratio — The ratio of the excavation span, diameter, or height to the equivalent excavation dimension. The excavation support ratio (which varies from 0.8 to 4.0) is a parameter used in the application of the rock-mass quality (Q) to the estimation of support requirements proposed by Barton et al. (1974).

exceedence probability — The probability that a particular value will be exceeded. Exceedence probability is the complement of cumulative probability.

exclusion area — The area surrounding a nuclear facility in which the licensee has the authority to control all activities, including the exclusion or removal of personnel and property from the area.

expected — Assumed to be probable or certain on the basis of existing evidence and in the absence of significant evidence to the contrary.

expected repository performance — The manner in which the repository is predicted to function, considering those conditions, processes, and events that are likely to prevail or may occur during the time period of interest.

exploratory shafts — Excavations into the host rock to the depth of the repository. The shafts will be large enough to allow people and test equipment to be transported from the surface to the underground excavations.

extensometer — An instrument used to measure strain.

extraction ratio — The ratio of the amount of rock removed to the total amount of rock available in a given area.

extrusive — Igneous rock that has been erupted onto the surface of the earth.

facies — The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of its origin, especially as differentiating the rock unit from adjacent or associated units.

fallout (radioactive) — Fission and activation products produced by the above-ground detonation of a nuclear device.

fanglomerate — A sedimentary rock consisting of slightly waterworn, heterogeneous fragments of all sizes, originally deposited in an alluvial fan and subsequently cemented into a firm rock.

far field — The portion of the geologic setting that lies beyond the near field.

fault — A fracture or zone of fractures along which there has been displacement of the sides relative to one another, parallel to the fracture or zone of fractures.

fault block — A structural unit of the earth's crust that is formed by faulting and is bounded completely or in part by faults. This structure behaves essentially as a unit during tectonic activity.

fault escarpment — See "fault scarp."

fault gouge — A soft, uncemented pulverized clayey or claylike material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault, and filling or partly filling a fault zone; a slippery mud that coats the fault surface or cements the fault breccia.

fault plane — The plane along which faulting has taken place.

fault scarp — The cliff or escarpment formed by a fault that reaches the earth's surface.

fault system — A system consisting of two or more fault sets that were formed at the same time.

faulting — The process of fracturing or displacement that produces faults.

favorable condition — A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular siting guideline can be met.

feldspar — A group of abundant rock-forming minerals of the general formula $MAl(Al,Si)_3O_8$, where M is potassium, sodium, calcium, barium, rubidium, strontium, or iron. Feldspars are the most widespread of any mineral group and constitute 60 percent of the earth's crust.

feldspathic — Containing feldspar as a principal constituent.

ferromagnesian — Containing iron and magnesium.

finding — A conclusion that is reached after evaluation.

finite-element computer code	A computer code that uses the finite-element method. The finite-element method is a method of numerical analysis that divides a region of interest into discreet elements and represents the behavior of the elements with a set of simultaneous equations. Solution of the set of equations yields the behavior at discreet points within the region of interest.
first-order fold	An original stage fold larger than subsequent folds that may occur on it. (See also "second-order fold.")
fission (nuclear)	The division of the atomic nuclei into nuclides of lower mass, accompanied by the emission of gamma rays, neutrons, and significant energy.
fission product	A nuclide produced by the fission of a heavier element.
fissure	A fracture or a crack in the earth's surface, along which there is a distinct separation.
flat-jack test	Testing apparatus used for the determination of in situ stresses or rock-mass deformability.
flexure-flow fold	A fold in which the mechanism of folding is flow within layers, resulting in thickening of hinge areas and thinning of limbs.
flooding potential	Areas susceptible to flooding by precipitation-, wind-, or earthquake-induced floods (i.e., floods resulting from dam failure, river blockage or diversion, or distantly or locally generated waves) are considered to have a flooding potential.
flood plain	As defined in 10 CFR Part 60, the lowland and relatively flat areas adjoining inland and coastal waters, including the flood-prone areas of offshore islands and, at a minimum, the area that is subject to a 1-percent or greater chance of flooding in any given year.
flow	See "basalt flow."
flow bottom	The lower portion of a basalt flow composed of one or a combination of breccia, ropy, glassy, vesicular, vuggy, or rubbly basalt. Flow bottom can also include glassy altered pillow basalt complexes.
flow contact	A planar or irregular surface where two different types or ages of rock meet (i.e., between two basalt flows).
flow interior	The zone within a basalt flow from the bottom of the flow top to the top of the flow top. It includes both the entablature and colonnade, as well as internal vesicular zones, etc.

flow structure — The structure of igneous rocks, generally but not necessarily restricted to volcanic rocks, in which the stream or flow lines of the magma (as evidenced by the orientation of the rock crystals) are revealed by alternating bands or layers of differing composition, crystallinity, or texture.

flow top — The upper portion of a basalt flow, composed of one or more of the following: breccia rubble, ropy, clinkery, vesicular, vuggy, or slabby basalt.

fluvial — Of or pertaining to rivers; growing or living in a stream or river; produced by the action of a stream or river.

flux — Rate of flow over a surface (quantity per unit area per unit time).

focal-mechanism solution — A double-couple solution obtained by using the first motion of arrival of P-waves at a particular seismic-recording station.

fold (geologic) — A curve or bend of a planar structure such as rock strata or bedding planes. A fold is usually a product of deformation.

fold belt — An essentially linear region that has been subjected to folding or deformation.

formation (geologic) — The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock generally characterized by some degree of internal lithologic homogeneity or distinctive features.

fracture — A general term for any break or discontinuity in a rock caused by mechanical failure resulting from stress, whether or not it causes displacement on either side large enough to be visible to the unaided eye. It may be a joint, fault, or fissure caused by geological or mechanical process and can range from microscopic to macroscopic and megascopic scales.

fracture permeability — The capacity of a fracture for transmitting a fluid; it is the measure of the relative ease of fluid flow under unequal pressure.

fuel assembly — An assembly of nuclear-fuel rods. Also called "fuel element."

fuel consolidation — The removal of spent-fuel rods from an assembly and repacking in a denser array to reduce the volume per metric ton of fuel.

fuel element — See "fuel assembly."

fuel rod	A long slender, cylindrical tube of stainless steel or Zircaloy containing nuclear fuel in the form of uranium oxide fuel pellets. Also called "fuel pin."
fuel reprocessing	The process whereby spent fuel is dissolved, waste materials are removed, and reusable materials are segregated for reuse.
fugitive emissions	Emissions of any pollutant, including fugitive dust, that do not pass through a stack, chimney, vent, or a functionally equivalent opening and are generated by activities necessary for the continued operation of the source.
gallery (geology)	(1) A horizontal or nearly horizontal underground passage, either natural or artificial. (2) A sub- sidiary passage in a cave at a higher level than the main passage.
gamma radiation	Electromagnetic ionizing radiation that is emitted during some types of radioactive decay processes. Gamma radiation can penetrate various thicknesses of absorbed material, depending mainly on the energy of the gamma ray and the composition of the material. Gamma radiation is mainly an external radiation hazard.
general siting guidelines	See "siting guidelines."
geochemistry	The study of the distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere and the chemical interactions between these phases.
geochronology	The study of time in relationship to the history of the earth.
geodetic survey	A survey of a large land area in which account is taken of the shape and size of the earth and corrections are made for the earth's curvature.
geodolite	An electro-optical distance-measuring instrument in which a modulated laser beam is projected from the instrument to a remote reflector from which it is returned to the instrument. Geodolite is a trade name.
geoelectric layer	One particular layer in a vertical distribution of layer thicknesses, electrical conductivities, dielec- tric permissivities, and magnetic permeabilities that are descriptive of the subsurface.

geoengineering	The application of geologic data, principles, and techniques to the study of naturally occurring rock and soil materials or ground water for the purpose of ensuring that geologic factors affecting the location, planning, design, construction, operation, and maintenance of engineering structures and the development of ground-water resources are properly recognized and adequately interpreted, used, and presented for use in engineering practice.
geohydrologic setting	The system of hydrologic units that is located within a given geologic setting.
geohydrologic system	The geohydrologic units within a geologic setting, including any recharge, discharge, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.
geohydrologic unit	An aquifer, a confining unit, or a combination of aquifers and combining units that constitutes a framework for a reasonably distinct component of a geohydrologic system.
geologic formation	Any igneous, sedimentary, or metamorphic rock represented as a unit in geologic mapping.
geologic repository	A system, requiring licensing by the Nuclear Regulatory Commission, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.
geologic-repository operations area	A radioactive-waste facility that is part of the geologic repository, including both surface and subsurface areas and facilities where waste-handling activities are conducted.
geologic setting	The geologic, hydrologic, and geochemical systems of the region in which a geologic-repository operations area is or may be located.
geologic system	The host rock or host-rock units and surrounding rocks that provide radionuclide containment and isolation.
geologic time scale	A system of subdividing geologic time, usually presented in the form of a chart showing the names of the various divisions of time, stratigraphy, or rock as currently understood.

geomechanics	The branch of geology that deals with the response of earth materials to deformational forces and embraces the fundamentals of structural geology.
geomorphic processes	Geologic processes that are responsible for the general configuration of the earth's surface, including the development of present landforms and their relationships to underlying structures, and processes that are responsible for the geologic changes recorded by these surface features.
geomorphology	The branch of geology that deals with the general configuration of the earth's surface; specifically, the study of the classification, description, nature, origin, and development of landforms.
geophone	See "seismometer."
geophysical	Pertaining to the properties of the earth related to its structure, composition, and development.
geophysical anomaly	An area or restricted portion of information derived from a geophysical survey that is different in appearance from the general pattern of information.
geophysical log	A graphic record of the measured or computed physical characteristics of the rock section encountered in a well, plotted as a continuous function of depth.
geophysical survey	The use of one or more geophysical techniques, such as earth current, electrical, gravity, magnetic, or seismic surveys, to gather information on subsurface geology.
geosyncline	A large, generally linear trough that deeply subsided over a long period of time and in which a thick sequence of stratified sediments accumulated.
geotechnical	Pertaining to the application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of the materials of the earth's crust.
geothermal gradient	The rate of increase in temperature of the earth with depth. The average geothermal gradient in the earth's crust is approximately 25°C per kilometer of depth.
geotransport	Movement of radionuclides through subsurface soils and rocks, especially the movement of radionuclides in ground water. Used in contrast to "biotransport."
getter	A material that selectively sorbs and holds particular elements (i.e., an Eh buffer is an oxygen getter). This term is particularly applicable to engineered barrier systems. (Adapted from metallurgical processes wherein a getter is used to remove impurities.)

glacio-eustatic	Pertaining to worldwide changes in sea level resulting from successive withdrawal and return of water to the oceans, which occurs during the growth and melting of ice sheets.
glaciofluvial	Of, pertaining to, produced by, or resulting from combined glacial meltwaters.
glomerocryst	An aggregate of crystals of the same mineral.
glomerophyric	A term applied to the texture of porphyritic igneous rocks containing closed clusters of equant crystals of the same mineral.
gneiss	A foliated rock formed by regional metamorphism, in which bands of granular materials alternate with bands of minerals with elongate prismatic habit.
gouge	The clay or clayey material in a fault zone. Also crushed rock along a fault slip.
graben	A usually elongated depression of the earth's crust between two parallel faults.
granite	A medium- to coarse-grained intrusive igneous rock consisting primarily of feldspar and quartz.
granite wash	A drillers' term for material eroded from outcrops of granite rock and redeposited to form rock having approximately the same major mineral constituents as the original rock.
grants equal to taxes	Grants made by the Secretary of Energy to each State and unit of general local government in which a site for a repository is approved equal to the amount such State and unit of general local government, respectively, would receive were they authorized to tax site characterization activities at such site, and the development and operation of such repository, as such State and unit of general local government tax and other real property and industrial activities occurring within such State and unit of general local government.
gravity survey	Measurements of the earth's gravitational field at a series of different locations. The purpose is to associate gravitational variations with differences in the distribution or densities of rock and hence rock types.
Great Basin	A subdivision of the Basin and Range province, located in southern Nevada in a broad desert region. The Yucca Mountain site is in the Great Basin.
ground magnetic survey	A determination of the magnetic field at the surface of the earth by means of ground-based instruments.

ground motion	The displacement of the ground due to the passage of elastic waves arising from earthquakes, explosions, seismic shots, and the like.
ground water	Water that occurs beneath the water table in soils and in geologic formations that are fully saturated.
ground-water basin	An underground structure with the character of a basin with respect to the collection, retention, and outflow of water.
ground-water flux	The rate of ground-water flow per unit area of porous or fractured media, measured perpendicular to the direction of flow.
ground-water recharge rate	The rate at which water is absorbed by the ground and later added to the zone of saturation.
ground-water residence time	The time that ground water remains in an aquifer or aquifer system.
ground-water sources	Aquifers that have been or could be economically developed as sources of ground water in the foreseeable future.
ground-water travel time	The time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the direction of flow, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.
grout	A mortar or cement-and-water mixture that is used to seal the walls of boreholes and shafts.
guidelines	See "siting guidelines."
Gulf interior region of the Gulf Coastal Plain	A region in northeastern Texas, northern Louisiana, and south-central Mississippi containing several hundred salt domes. Also called the "Gulf Coastal salt-dome basin" or simply the "Gulf interior region." The Richton Dome site is located in this region.
half-life	The time it takes for one-half of the radioactive atoms initially present in a sample to decay. Each radionuclide has a characteristic but constant half-life. (See also "biological half-life.")
hanging wall	The overlying side of a fault or other structure.
halite	Rock salt, which consists of sodium chloride (NaCl).

Hanford Site	A DOE reservation covering nearly 600 square miles in south-central Washington. A portion of this reservation has been identified as a potentially acceptable site in basalt and is called the "Hanford site" or the "reference repository location."
head, hydraulic	See "hydraulic potential" or "hydraulic head."
headframe	The steel or timber frame at the top of a shaft that supports the sheave or pulley for the hoisting cables and serves other purposes.
heat emission	For the purpose of establishing waste-package acceptance criteria, the total amount of heat dissipated from a package of radioactive waste.
heavy metal	All uranium, plutonium, or thorium placed into a nuclear reactor.
high-level radioactive waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.
High Plains aquifer	An unconfined aquifer consisting of the Ogallala Formation and the Dockum Group. It is the uppermost of the three major hydrogeologic units beneath the Southern High Plains.
highly populated area	Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census-designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein.
hinge zone	A zone along the boundary between a tectonically stable region and a region moving upward or downward.
historical seismicity	Earthquakes that occurred during recorded history, including those reported before the existence of seismographs (preinstrumental) and those recorded by seismographs (instrumental).
Holocene	An epoch of the Quaternary Period, from the end of the Pleistocene to the present.

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homocline	A general term for a rock unit in which the strata have the same dip (e.g., on a limb or a fold, a fault block, a monocline, or an isocline).
Hooke's law	In elastic deformation, the strain is linearly proportional to the applied stress.
horizon	(1) In geology, a given definite position or interval in the stratigraphic column. (2) In this document, a specific underground level or elevation.
host rock	The rock in which the radioactive waste will be emplaced; specifically, the geologic materials that will directly encompass and will be in close proximity to the underground repository.
hot cell	A highly shielded compartment in which highly radioactive material can be handled, generally by remote control.
hundred-year storm	A storm whose intensity is such, on a statistical basis, that it is expected to recur only once every 100 years.
hyalocrystalline	A textural term referring to an igneous rock in which glass groundmass constitutes approximately three- eighths to five-eighths (by volume) of the rock.
hydraulic conductivity	The rate of water flow through a given cross section of rock in a unit time under a unit hydraulic gradient measured perpendicular to the direction of flow. Synonymous with the ease of ground-water movement.
hydraulic gradient	A change in the static pressure of ground water, expressed in terms of the height of water above a datum per unit of distance in a given direction.
hydraulic head	The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of elevation head, pressure head, and velocity head.
hydraulics	An engineering discipline that deals with the statics and dynamics of fluids.
hydrofracturing	A technique for measuring in situ stress by artificially inducing fractures hydraulically in a rock mass.
hydrogeologic unit	Any soil or rock unit or subsurface zone that affects the storage or movement of ground water by its porosity or permeability.
hydrograph	A graph showing stage, flow, velocity, or other characteristics of water with respect to time.

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hydrologic modeling	The process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of ground water.
hydrologic process	Any hydrologic phenomenon that exhibits a continuous change in time, whether slow or rapid.
hydrologic properties	The properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.
hydrologic regime	The distribution, characteristics, and interrelationships of the aqueous components of the geologic environment.
hydrologic transport	Transport of solutes through a geologic medium caused by the movement of ground water.
hydrology	The study of global water and its properties, circulation, and distribution, from the time it falls as rain water until it is returned to the atmosphere through evapotranspiration or flows into the ocean.
hydrostatic pressure	The pressure exerted by the water at any given point in a body of water that is at rest.
hydrostratigraphic unit	A term used for a body of rock having considerable lateral extent and composing a geologic framework for a reasonably distinct hydrologic system.
hydrothermal	An adjective applied to heated or hot solutions, to the processes with which these solutions are associated, and to the rocks, ore deposits, and alteration products produced by these solutions.
hydrothermal alteration	Alteration of rocks or minerals by the reaction of heated water with preexisting solid phases.
hydrothermal reactions	The reaction of materials under aqueous conditions at elevated temperatures and pressures. A component of hydrothermal test mixtures is usually the host rock, but such mixtures may contain any or all waste package components.
hypocenter	The focus or specific point at which initial rupture occurs in an earthquake.
igneous activity	The emplacement (intrusion) of molten rock (magma) into material in the earth's crust or the expulsion (intrusion) of such material onto the earth's surface or into its atmosphere or surface water.

igneous rock	A rock that solidified from molten or partly molten material (i.e., from a magma). Igneous rock is one of the three main classes into which rocks are divided, the others being metamorphic rock and sedimentary rock.
image analysis	The quantitative analysis of a specimen made by using the optical counterpart of the specimen, produced by the enhanced reflection or refraction of light when focused by an electronic optical system.
imbricate faulting	A zone of closely spaced faults exhibiting a structure of tabular masses that overlap one another as shingles on a roof.
immobilization	Treatment or emplacement of wastes to impede the movement of their radionuclides.
important to safety	The engineered structures, systems, and components essential to the prevention or mitigation of any accident that could result in a radiation dose to the whole body or an organ of 0.5 rem or more at or beyond the nearest boundary of the controlled area at any time until the completion of permanent closure.
impoundment	The process of forming a lake or pond by a dam, dike, or other barrier; also, the body of water so formed.
indirect employment multiplier	Figure based on the estimated ratio of project employment to the local employment resulting from both the project and project employees with their families purchasing goods and services in the area. It is multiplied by the project employment to give indirect employment growth.
indirect work force	People hired for jobs that are available because of the repository location but not at its facilities; for example, jobs with repository suppliers, town services, or retail business.
induration	The hardening of rock material by heat, pressure, or the introduction of some cementing material.
in-migrants	Workers and their families relocating permanently or temporarily to the vicinity of the site. During construction and operation, these workers and their families are considered to be in-migrants for as long as they are present.
in-migration	Moving into a region or a community, especially as part of a large-scale and continuing movement of population.
in-migration model	The analytical or mathematical representation or quantification of in-migration.

in situ — In its natural or original position. The phrase distinguishes in-place experiments, rock properties, and the like from those conducted or measured in the laboratory.

in situ stress — The magnitude and state of ground stress in a rock mass. The inherent stress in a rock mass at depth.

in situ tests — Tests that are conducted with the subject material in its original place (i.e., at the repository site and depth).

institutional controls — Administrative controls, records, physical constraints, and combinations thereof that would limit intentional or inadvertent human access to the waste emplaced in a repository.

instrumental seismicity — Earthquakes recorded on a seismograph (an instrument designed to detect and record earthquakes).

intact-rock failure envelope — The intact-rock failure envelope represents the calculated rock strength at various levels of confining stress.

intensity (earthquake) — A measure of the effects of an earthquake on people, on structures, and on the earth's surface at a particular location; quantified by a numerical value on the modified Mercalli scale.

interbed — A bed of one kind of rock material, typically relatively thin, occurring between or alternating with beds of another kind.

intercalated — Occurring between two rock layers or within a series of layers.

intergranular — Of or pertaining to the ophitic texture of an igneous rock in which the augite occurs as an aggregation of grains in the interstices of a network of feldspar laths. The interstitial augite forms a relatively small proportion of the rock.

internal structures — As pertains to internal characteristics of basalt flows forming during emplacement and cooling; include flow-top breccias, vesicular zones, pillow zones, and cooling-joint patterns such as in the entablature and colonnade.

intersertal — A term applied to porphyritic igneous rock in which the groundmass occupies the interstices between unoriented feldspar laths, with the groundmass forming a relatively small proportion of the rock.

interstice — An opening or space between rock materials or soil particles.

interstitial compounds	Interstitial deposits formed after the rock formations whose pores they have filled.
intrusive	Of or pertaining to the emplacement of magma in preexisting rock.
inversion	An atmospheric condition where a lower layer of cool air is trapped below an upper layer of warm air so that the cooler air cannot rise. Since inversions spread air horizontally, contaminating substances cannot be widely dispersed.
ion exchange	A chemical reaction in which mobile ions from a solid are exchanged for ions of like charge in a solution.
ionizing radiation	Any radiation displacing electrons from atoms or molecules, thereby producing ions (e.g., alpha, beta, and gamma radiation).
isolation	Inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.
isolation barrier	The earth material around the underground disposal rooms; it acts to prevent radioactivity from entering the biosphere.
isopach	A line on a map drawn through points of equal thickness of a designated unit.
isopach map	A map that shows the thickness of a geologic unit throughout a geographic area by means of isopach lines at regular intervals.
isopleth	A general term for a line on a map or chart along which all points have a numerically specified constant or equal value of any given variable, element, or quantity with respect to space or time.
isotherm	A line joining data points on a map or chart having the same temperature.
joint	A surface of fracture or parting in rock, without displacement; the surface is often a plane and may occur with parallel joints to form a joint set.
jointing, columnar	See "columnar jointing."
K_d	See "distribution coefficient."

kinematic analysis — The analysis of displacements and strains; it is based on geometric analysis plus a number of assumptions regarding the manner in which geometrical relationships serve to indicate displacements.

kriging — An interpolation technique that can provide unbiased estimates of a spatially distributed quantity at points or in regions where data are lacking. The kriging algorithm is designed to minimize the error of each estimate.

lahar — A type of mudflow composed chiefly of volcaniclastic materials on the flank of a volcano.

L_{dn} — Day-night equivalent sound level: 24-hour equivalent sound level with a 10-dBA penalty applied for the nighttime hours (10 p.m. to 7 a.m.).

L_{ed} — Energy-equivalent sound level: the average of the time-varying sound energy.

lacustrine — Pertaining to, produced by, or inhabiting a lake or lakes.

leachate — A solution obtained by leaching; for example, water that has percolated through soil containing soluble substances and thus contains certain amounts of these substances in solution.

leaching — The dissolution of soluble constituents of a solid material (e.g., the waste to be emplaced in a repository) by the action of percolating water or chemicals.

leakage — Ground-water flow across or through a rock zone of low permeability.

level 1 — A specific finding on a disqualifying condition as described in Appendix III of the siting guidelines. A level 1 finding means "the evidence does not support a finding that the site is disqualified."

level 2 — A specific finding on a disqualifying condition as described in Appendix III of the siting guidelines. A level 2 finding means "the evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified."

level 3 — A specific finding on a qualifying condition as described in Appendix III of the siting guidelines. A level 3 finding means "the evidence does not support a finding that the site is not likely to meet the qualifying condition."

level 4	A specific finding on a qualifying condition as described in Appendix III of the siting guidelines. A level 4 finding means "the evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition."
license application	An application for a license from the Nuclear Regulatory Commission to construct a repository.
licensing	The process of obtaining the permits and authorizations required to site, construct, operate, close and decommission a repository.
lignite	A brownish-black coal in which the alteration of vegetable material has proceeded farther than in peat, but not so far as subbituminous coal.
lineament	A linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.
linear energy transfer	A measure of the energy deposited per unit of path length.
linear expansion	The change in the length of a solid due to a change in temperature. The coefficient of linear expansion is the change in a solid's unit length per 1 degree change in temperature.
lithology	The study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts.
lithophysae	Hollow bubblelike structures in rocks; composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.
lithosphere	The solid part of the earth, including any ground water contained within it.
lithostatic pressure	The confining pressure at depth in the crust of the earth from the weight of the overlying rocks.
loess	A homogeneous unstratified deposit of windblown dust composed mainly of sand and silt.
log	A record that shows the character of rock being drilled, the drilling process, the drilling tools used, mud weight and condition, personnel on duty, and any pertinent or unusual events occurring during the drilling.
logging	Recording observations, conditions, activities, or measurements.

low-level transuranic waste	See "contact-handled transuranic waste."
low-level waste	Radioactive material that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in Section 11a(2) of the Atomic Energy Act of 1954.
mafic	Said of an igneous rock composed chiefly of dark ferromagnesian minerals.
magma	Naturally occurring mobile rock material, generated within the earth and capable of extrusion and intrusion, from which igneous rocks are thought to have been derived through solidification and related processes.
magnetic survey	A survey made with a magnetometer on the ground or in the air; it reveals local variations in the intensity of the magnetic field.
magnetometer	Instrument that measures the earth's magnetic field or the magnetic field of a particular rock.
magnetotelluric method	A geophysical surveying method that measures the natural electric and magnetic fields of the earth.
magnitude	The measure of the strength of an earthquake; related to the energy released in the form of seismic waves. Magnitude is quantified by a numerical value on the Richter scale.
man-rem	The unit of population dose. It is obtained by multiplying the average dose equivalent to a given organ or tissue (measured in rem) by the number of persons in a population.
maximally exposed individual	A hypothetical person who is exposed to a release of radioactivity in such a way that he receives the maximum possible individual radiation dose or dose commitment. For instance, if the release is a puff of contaminated air, the maximally exposed individual is a person at the point of the largest ground-level concentration and stays there during the whole time the contaminated-air cloud remains above. This term is not meant to imply that there really is such a person; it is used only to indicate the maximum exposure a person could receive.
maximum credible earthquake	The strongest earthquake that, considering the earthquake history and the tectonic setting of a place, could be reasonably expected to occur during the preclosure and postclosure phases of a repository.

maximum drawdown — The greatest lowering of the water table or potentiometric surface caused by pumping (or artesian flow).

maximum individual dose — The highest radiation dose delivered to the whole body or to an organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed individual, is one whose location, activities, and habits maximize the dose.

maximum permissible concentration — The average concentration of a radionuclide in air or water to which a worker or member of the general population may be continuously exposed without exceeding regulatory limits on external or internal radiation doses.

member of the public — Any individual who is not engaged in operations involving the management, storage, and disposal of radioactive waste. A worker so engaged is a member of the public except when on duty at the geologic-repository operations area.

Mercalli intensity — A scale for measuring earthquake intensity in terms of the effects perceived by people.

mesostasis — The last-formed interstitial material of an igneous rock.

Mesozoic — An era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic, or from about 225 million to about 65 million years ago.

metamorphic rock — All rocks that were formed in the solid state in response to pronounced changes in temperature, pressure, and chemical environment--changes that take place, in general, below the surface zones of weathering and cementation.

metamorphism (geologic) — The mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions imposed at depth below the surface zones of weathering and cementation, which differ from the conditions under which the rocks originated.

metasedimentary — Sedimentary rocks altered by the effects of heat or pressure or both.

metavolcanic — Volcanic rocks altered by the effects of heat or pressure or both.

meteorological monitoring station — A tower containing instruments to measure wind speed, wind direction, temperature at different heights, dew point, etc.

mica — A group of minerals consisting of complex silicates with perfect basal cleavage; they split into thin elastic laminae and range from colorless to black.

microearthquake	An earthquake that is not felt or has a magnitude of less than 3 on the Richter scale. Also called "microseism."
millidarcy	A unit of measurement of fluid permeability equivalent to 0.001 darcy.
millirem	1 millirem is 1/1,000 of a rem.
mined geologic disposal system	See "repository system."
mineral	A naturally occurring inorganic element or compound with an orderly internal structure and a characteristic chemical composition, crystal form, and physical properties.
mineralogy	The study of minerals. Also the formation, occurrence, properties, and composition of the minerals that make up a rock.
Miocene	An epoch of geologic time in the Tertiary Period, after the Oligocene Epoch and before the Pliocene Epoch.
mitigation	(1) Avoiding the impact altogether by not taking a certain action or parts of an action. (2) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (3) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (4) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (5) Compensating for the impact by replacing or providing substitute resources or environments.
mixing height (or depth)	The height above the surface of the earth defining a layer where vigorous vertical mixing of air occurs; this mixing layer represents the vertical extent to which pollutants can be mixed in the atmosphere.
modal analysis	The analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentage. See "conceptual model," "tectonic model."
model	A conceptual description and the associated mathematical representation of a system, component, or condition. It is used to predict changes in the system, component, or condition in response to internal or external stimuli as well as changes over time and space. An example is a hydrologic model to predict ground-water travel or radionuclide transport from the waste-emplacement area to the accessible environment.
modeling, hydrologic	See "hydrologic modeling."

monitoring	Routine measuring of the quantity and type of radionuclide releases from a waste-management facility or measuring of the changes in the physical, chemical, or biological characteristics of the site and the surrounding area.
modified Mercalli scale	An earthquake-intensity scale with 12 divisions ranging from I (not felt by people) to XII (damage nearly total); commonly abbreviated MM.
modulus of deformation	A term used for materials that deform in a manner other than according to Hooke's law; also called "modulus of elasticity" (see "Hooke's law").
modulus of elasticity	See "elastic modulus."
monocline	A downward flexure in otherwise horizontal strata without any corresponding upfold to form a syncline or anticline. Generally a large feature of gentle dip.
monolithic structure	A structure formed or composed of rock material without joints or seams.
moraine	A mound, ridge, or other accumulation of unsorted, unstratified rock material left at the margins of a retreating glacier.
morphology	The study of topographic features; the form of land.
muck	Broken rock that results from mining.
mudstone	A dark-gray, fine-grained shale that decomposes into mud when exposed to the atmosphere.
multibarrier system	A system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.
multiwell aquifer test	A test to determine an aquifer's capacity; it involves adding or withdrawing measured quantities from more than one well and measuring the resulting changes in hydraulic head.
natural background radiation	See "background radiation."
natural barrier	The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that, individually and collectively, act to minimize or preclude radionuclide transport.

natural gamma log	A log of the natural radioactivity of the rocks traversed in a borehole obtained by measuring naturally emitted gamma rays.
natural system	A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. Includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provides conditions that will minimize the potential for human interference in the future.
near field	The region where the natural geohydrologic system has been significantly perturbed by the excavation of the repository and the emplacement of the waste.
neutron log	A radioactivity log that measures the intensity of neutrons or gamma rays produced when rocks around a borehole are bombarded by neutrons from a synthetic source.
Near-Surface Test Facility	A full-scale demonstration facility located in Gable Mountain on the Hanford Site; it was constructed to examine how basalt is affected by heat and radiation-induced stresses from the emplacement of radioactive waste.
neutron probe	A probe used to measure the intensity of radiation for a neutron log.
Nevada Test Site	An area in Clark and Nye Counties in southern Nevada; it is dedicated to the underground testing of nuclear weapons.
noble gases	A group of gases that includes helium, neon, argon, krypton, xenon, and sometimes radon. Also known as inert gases, these gases have great stability and extremely low reaction rates.
nonconformity	An unconformity in which stratified rocks above the surface rest on unstratified, older rocks.
nonradiological risk	A risk from sources other than exposure to radiation.
normal fault	A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45 to 90 degrees.
occupational dose	The radiation dose received by a person in a restricted area or in performing work duties involving exposure to radiation.

operating-basis earthquake	The earthquake that, considering the regional and local geology, seismology, and the specific characteristics of local subsurface material, could reasonably be expected to affect the site during the operating life of a facility.
operational phase	The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning.
ophitic texture	Said of the texture of an igneous rock in which lath-shaped plagioclase crystals are partially or completely included in pyroxene crystals, typically augite.
orogenic	Of or pertaining to the process of mountain formation, especially by folding of the earth's crust.
outcrop	The part of a geologic formation or structure that appears at the surface of the earth.
outwash	Sorted and stratified rock material deposited by proglacial meltwater streams.
overburden	Loose soil, sand, gravel, or other unconsolidated material that overlies bedrock.
overcoring	A process that determines stress components in a rock mass. The process consists of drilling a small-diameter borehole and inserting deformation-sensing devices. A larger hole is then drilled concentrically with the first hole, which relieves the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships.
overthrust	A low-angle thrust fault of a large scale, with displacement generally measured in kilometers.
oxidation-reduction reaction	A chemical reaction in which one or more electrons are transferred between two or more chemical constituents of the system.
oxygen chemical potential	See "Eh."
package	See "waste package."
packaging	The container, any overpacks, and their contents, excluding radioactive materials and their encapsu- lating matrix but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for absorbing mechanical shock, external fittings or handling devices, neutron absorbers or moderators, and other supplementary equipment that surrounds the radioactive material.

packer	A device used in drilled holes to isolate one part of a borehole from another in order to carry out studies of particular formations or parts thereof.
packer-injection tests	A series of tests whereby a liquid (usually water) or gas is injected into a sealed off or isolated portion of a borehole or well to obtain data on formation permeability, fracture flow, and the like.
packing	The part of the waste package that contributes to the performance of the total waste package by minimizing ground-water interaction with the container and the waste, limiting radionuclide transport, and altering ground-water chemistry to minimize the degradation of the waste form and the container as well as radionuclide solubility.
palagonite	A weathered hydrated basaltic glass commonly formed when molten basalt that entered water has become weathered; indicative of an aqueous environment, often associated with pillow lava.
paleoclimate	A climate of the geologic past.
paleoecology	The study of the relationship between ancient organisms and their environment.
paleohydrology	The study of ancient hydrologic features preserved in rock.
paleomagnetism	The study of the natural remnant magnetization of the earth to determine the intensity and direction of the earth's magnetic field in the geologic past.
paleontology	The study of life of the geologic past based on fossilized plant and animal remains.
paleosol	A buried soil of the geologic past.
Paleozoic	The era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic or from about 570 million to 225 million years ago.
paludal	Pertaining to a marsh or swamp.
palynology	The study of spores, pollen, and microorganisms that occur in sediments.
panel	A collection of underground rooms connected by a common access and common ventilation corridors.
Paradox Basin	A 25,900-square-kilometer (10,000-square-mile) area in southeastern Utah and southwestern Colorado; it is underlain by bedded salt and a series of salt-core anticlines. The Davis Canyon site is in the Paradox Basin.

parasitic anticline — An anticlinal fold occurring on one of the flanks of a larger anticline.

particulates — Finely divided particles suspended in a gaseous medium, such as dust in air.

Pasco Basin — A structural and topographic basin in the western Columbia Plateau. The Hanford Site and the reference repository location are in the Pasco Basin.

passive institutional controls — (1) Permanent markers placed at a disposal site. (2) Public records or archives. (3) Federal Government ownership or control of land use. (4) Other methods of preserving knowledge about the location, design, or contents of a disposal system.

pathway — As related to waste disposal, possible or potential routes by which wastes might reach the accessible environment.

pedology — The study of the morphology, origin, and classification of soils.

perched ground water — Unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Perched ground water is supported by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

percolate — In hydrology, the passage of a liquid through a porous substance; e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soil; i.e., the slow seepage of water through soils or porous deposits.

performance assessment — Any analysis that predicts the behavior of a system or system component under a given set of constant or transient conditions. For the repository, such an analysis identifies the events and processes that might affect the disposal system, examines their effects on its barriers, and estimates the probabilities and consequences of the events.

performance confirmation — A program of test, experiments, and analyses required by the Nuclear Regulatory Commission and conducted to evaluate the accuracy and adequacy of the information used to determine reasonable assurance that the postclosure performance objectives can be met.

performance criterion — A criterion establishing qualitative operational, safety, or environmental limits.

periglacial — Pertaining to the areas, conditions, processes, and deposits marginal to an ice sheet or glacier.

permanent closure	See "closure."
permeability	The capacity of a medium like rock, sediment, or soil to transmit ground water. Permeability depends on the size and shape of the pores in the medium and the manner in which the pores are interconnected.
Permian Basin	A region in the Central United States where, during Permian time 280 to 225 million years ago, there were many shallow seas that laid down vast beds of salt and other evaporites. The Deaf Smith site is in the Permian Basin.
permissible dose	That dose of ionizing radiation that, in light of present knowledge, carries negligible probability of causing a severe somatic injury or a genetic effect.
petrography	The branch of geology that deals with the description and systematic classification of rocks, especially igneous and metamorphic rocks and especially by the microscopic examination of thin sections.
petrology	The branch of geology that deals with the origin, occurrence, structure, and history of rocks.
pH	A measure of the acidity or alkalinity of a solution.
phaneritic	A textural term pertaining to crystals or grains in igneous rocks that are visible to the unaided eye.
phenocryst	A term applied to any large, conspicuous crystal in an igneous rock.
phosphatic rock	Any rock that contains one or more phosphatic minerals, especially apatite.
photogrammetry	The science and art of obtaining reliable measurements from photographs.
photolineament	A lineament observed in photographic images that is a mappable simple or composite feature of a surface; its parts are aligned in a rectilinear or slightly curvilinear relationship, and it differs distinctly from adjacent features.
physiography	The descriptive study of landforms as opposed to geomorphology, which is the interpretive study of land forms.
physiographic province	A region in which all parts are similar in geologic structure and climate and which consequently had a unified geomorphic history.

piezometer — A tube or pipe in which the elevation of water level can be determined. A piezometer must be sealed along its length, and it must be open to water flow at the bottom and to the atmosphere at the top.

piezometric surface — See "potentiometric surface."

pillar — A solid mass of rock left standing to support a mine roof.

pillow lava — Basaltic material congealed in rounded masses, indicative of subaqueous flows or eruptions, occurring mostly in basalts.

plagioclase — An isomorphous series of (solid solution) triclinic feldspar minerals that form the group of common rock-forming minerals; the silicates of varying mixtures of sodium, calcium, and aluminum, ranging from albite, $NaAlSi_3O_8$, to anorthite, $CaAl_2Si_2O_8$.

plasticity — The property of a material that enables it to undergo permanent deformation without appreciable volume change or elastic rebound without rupture.

plate bearing test — A procedure performed in small tunnels or adits to measure the deformation characteristics of a rock mass.

platform — A general term for any level or nearly level surface under water.

playa — The lowest central portion of an arid basin that is dry and totally barren most of the time, but is occasionally flooded. Clay and silt are the principal constituents, often resulting from lakes formed in Pleistocene time.

Pleistocene — The first epoch before the Holocene of the Quaternary Period.

Pliocene — The latest epoch of geologic time in the Tertiary Period, preceded by the Miocene Epoch and followed by the Pleistocene Epoch.

plug (geologic) — (1) The vertical pipe-like magnetic body representing the conduit of a former volcanic vent. (2) A crater filling of lava, the surrounding material of which has been removed by erosion. (3) A mass of clay, sand, or other sediment filling the part of a stream channel abandoned by the formation of a cutoff.

plug (shaft or borehole) — A watertight seal in a shaft formed by removing the lining and inserting a concrete and/or metal dam, or by placing a plug of clay over ordinary debris used to fill the shaft up to the location of the plug.

pluvial — Said of a geologic episode, change, process, deposit, or feature resulting from the action or effects of rain. Also said of a climate characterized by relatively high amounts of precipitation. More broadly, pertaining to rain or other form of precipitation.

point source — A source of effluents small enough to be treated as if it were a point.

poison — Any material that has a high neutron-absorption cross section and, by absorbing neutrons unproductively, removes them from the fission chain reaction, thus decreasing the radioactivity.

Poisson's ratio — The ratio of the lateral unit strain to the longitudinal unit strain in a body that has been stressed longitudinally within its elastic limit.

population center — A densely populated area of 25,000 or more inhabitants.

population dose — The sum of the radiation doses received by the individual members of a population exposed to a particular source or event. It is expressed in units of man-rem.

pore — Any small open space, generally one that admits the passage or absorption of liquid, within the rock or soil.

porosity — The ratio of the total volume of interstices in rock or soil to its total volume, usually expressed as a percentage.

porosity log — A record of pore volume per unit volume of formation; it is made from a sonic log, density log, neutron log, or resistivity log.

porphyritic — A texture of igneous rock in which large crystals are set in a finer groundmass that may be crystalline or glassy or both.

postclosure — Of or pertaining to the time, conditions, or events after the closure of the repository.

potable water — Water that is safe and palatable for human use.

potentially acceptable site — Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.

potentially adverse condition — A condition that is presumed to detract from expected system performance unless further evaluation, additional data, or the identification of compensating or mitigating factors indicates that its effect on the expected performance of the repository system is acceptable.

potentially disruptive processes and events	Natural processes and events or processes and events initiated by human activities, affecting the geologic setting that are judged to be reasonably unlikely during the period over which the intended performance objective must be achieved, but are nevertheless sufficiently credible to warrant consideration.
potentiometric surface	The surface to which water from a given aquifer will rise by hydrostatic pressure. This surface is usually represented as a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point.
Precambrian	All geologic time, and it's corresponding rocks, that elapsed before the beginning of the Paleozoic era (the Paleozoic era began about 570 million years ago).
precipitation (geochemical)	The process by which mineral constituents are separated from magma or from a solution by evaporation to form igneous rocks.
preclosure	Of or pertaining to the time, activities, operations, and conditions before and during the closure of the repository.
pressurized water reactor	A nuclear reactor that uses pressurized water to generate electricity.
pre-waste-emplacement	Of or pertaining to geologic conditions before waste emplacement.
primary sector	The businesses that predominantly sell their goods and services to individuals and businesses outside the local economy. (See "secondary sector.")
prime farmland	Land with the best physical and chemical characteristics for producing agricultural crops with minimum use of fuel, fertilizers, pesticides, and labor and without intolerable soil erosion, as determined by the Secretary of Agriculture pursuant to the Farmland Protection Policy Act of 1982 (Public Law 97-98). Prime farmland includes land that has these characteristics and is being used to produce livestock and timber, but it excludes land already in, or committed to, urban development or water storage.
principal borehole	Borehole RRL-2; designated the principal borehole because it is the most important borehole for drilling the exploratory shafts.
probable maximum flood	A statistical representation of the greatest flood expected ever to occur at a specific location.
probable maximum precipitation	A statistical representation of the most precipitation that can reasonably be expected in a given area.

protected area	An area encompassed by physical barriers and to which personnel access is controlled.
protected species	Plants and animals officially listed by the U.S. Fish and Wildlife Service. Species listed by the States as rare, threatened, or endangered are not included unless they are also on the Federal list.
pyrite	A common brass-yellow mineral with the chemical composition of iron sulfide (FeS_2).
pyroclast	An individual particle ejected during a volcanic eruption.
pyroxene	A group of dark-colored rock-forming silicate minerals that are closely related in crystal form and composition.
quadrangle (geologic)	A tract of country represented by one of a series of map sheets published by the U.S. Geological Survey.
qualified site	A site that, having been characterized, is considered to be technically suitable for a repository.
qualifying condition	A condition that must be satisfied for a site to be considered acceptable with respect to a specific siting guideline.
quality assurance	All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.
quality control	Quality-assurance actions that provide a means to control and measure the characteristics of an item, process, or facility to established requirements.
quartz	Crystalline silica (SiO_2); an important rock-forming mineral.
quartzite	A metamorphic rock consisting mainly of quartz grains of equal size, formed by the recrystallization of sandstone by regional or thermal metamorphism.
Quaternary faults	Faults that formed or experienced movement during the Quaternary Period.
Quaternary Period	The second part of the Cenozoic Era (after the Tertiary), beginning about 1.8 million years ago and extending to the present.
rad	The basic unit of the absorbed dose of ionizing radiation. A dose of 1 rad equals the absorption of 100 ergs of radiation energy per gram of absorbing material.

radiation (ionizing)	Particles and electromagnetic energy emitted by nuclear transformations that are capable of producing ions when interacting with matter; gamma rays and alpha and beta particles are primary examples.
radiation zone	An area that contains radioactive materials or radiation field in quantities significant enough to require the control of personnel entry to the area.
radioactive decay	See "decay."
radioactive material	In general, any material that spontaneously emits nuclear particles or rays from the nuclei of its atoms.
radioactive waste	High-level radioactive waste, spent nuclear fuel, and other radioactive materials that are received for emplacement in a geologic repository.
radiological risk	A risk derived from exposure to radioactive materials.
radiolysis	The decomposition (splitting) of a chemical molecule (often the water molecule) by exposure to radiation.
radiometric dating	The calculation of the age of a material by a method that is based on the decay of radionuclides that occur in the material.
radionuclide	An unstable radioactive isotope that decays toward a stable state at a characteristic rate by the emission of ionizing radiation.
radionuclide retardation	The process or processes that cause the time required for a given radionuclide to move between two locations to be greater than the ground-water-travel time because of physical and chemical interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels.
rain shadow	A very dry region on the lee side of a topographic obstacle, usually a mountain range, where the rainfall is noticeably less than that on the windward side.
reasonably achievable	Mitigation measures or courses of action shown to be reasonable considering the costs and benefits in accordance with the National Environmental Policy Act of 1969. (See "as low as reasonably achievable.")
reasonably available technology	Technology which exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.

reasonably foreseeable releases	Releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 years.
recharge (hydrologic)	The process by which water is absorbed and added to the zone of saturation, either directly into a geologic formation, indirectly by way of another formation, or indirectly through unconsolidated sediments.
recharge area	In ground-water hydrology, the area where surface water enters an aquifer.
redox	See "oxidation-reduction reaction."
reduction (chemical)	A decrease in the oxidation state of an element or chemical compound.
redundant equipment or system	Any piece of equipment or any system that duplicates the essential function of any other piece of equipment or system and can perform the entire function regardless of the operating state of the other.
reference repository location	The potentially acceptable site on the DOE's Hanford Site. Also called the "Hanford site."
regolith	The superficial mantle of unconsolidated debris that nearly everywhere covers the bedrock and forms the surface of the land. In the Pasco Basin, the basin-filled sediments that overlie the basalt. (See also "overburden.")
regulated area	An area to which access is limited or controlled.
regulatory agency	The government agency responsible for regulating the use of sources of radiation or radioactive materials or emissions and responsible for enforcing compliance with such regulations.
regulatory guide	One of a series of official Nuclear Regulatory Commission guides prescribing standards and recommendations for nuclear facilities.
relative porosity	The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.
release limit	A regulatory limit on the concentration or amount of radioactive material released to the environment; usually expressed as a radiation dose.

rem	A unit dose of ionizing radiation that has the same biological effect as 1 roentgen of x-rays; 1 rem approximately equals 1 rad for x-, gamma, or beta radiation. Thus, a rem is a unit of individual dose that allows a comparison of the effects of various radiation types as well as quantities.
remotely handled transuranic waste	Transuranic waste that requires shielding in addition to that provided by its container in order to protect people nearby.
repository	See "geologic repository."
repository closure	See "closure."
repository construction	All excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site-characterization activities.
repository horizon	The horizontal plane within the host rock where the location of the repository is planned.
repository operation	All of the functions at the site leading to and involving radioactive-waste emplacement in the underground repository, including receiving, transporting, handling, emplacing, and, if necessary, retrieving the waste.
repository support facilities	All permanent facilities constructed to support site characterization and repository construction, operation, and closure, including surface structures, utility lines, roads, railroads, but excluding the underground repository.
repository system	The geologic setting at the site, the waste package, and the repository, all acting together to contain and isolate the waste.
reprocessing	See "fuel reprocessing."
residual saturation	The minimum saturation that occurs due to gravitational forces alone in the absence of recharge.
residual uncertainty	Those inherent uncertainties in data, modeling, and assumed future conditions that cannot be eliminated.
restricted area	Any area to which access is controlled by the DOE for purposes of protecting of individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

retention pond	An earthen structure designed to hold stormwater runoff; sometimes used to mean an evaporation pond.
retrievability	The capability to remove waste from its place of isolation in accordance with preestablished criteria for the method and the rate of removal.
retrieval	The act of intentionally removing radioactive waste before repository closure from the underground location at which the waste had been previously emplaced for disposal.
reverse fault	A fault in which the hanging wall appears to have moved upward relative to the footwall.
rhyolitic	Characteristic of a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture with crystals of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass (rhyolite).
Richter magnitude	See "Richter scale."
Richter scale	A scale for measuring the energy released by an earthquake. It was devised in 1935 by the seismologist C. F. Richter.
rift (geologic)	A long, narrow trough of regional extent, bounded by normal faults, often associated with volcanism.
right-lateral fault	A fault, the displacement of which is right-lateral separation. In plan view, the apparent movement of the side opposite the observer is to the right.
right-lateral offset	See "right-lateral fault."
riparian	Relating to or living or located on the bank of a natural water course (e.g., a river).
risk	The product of the probability and the consequences of an event.
rock bolt	A bar, usually constructed of steel, that is anchored into predrilled holes in rock as a support device.
rock burst	A sudden yielding that occurs when a volume of rock is strained beyond its elastic limit and the accompanying failure is such that the accumulated energy is released instantaneously. A rock burst can vary from the splitting off of small slabs of rock from a mine wall to the collapse of large pillars, roofs, or other massive parts of a mine.

rock-mass quality	A description of the physical characteristics and mechanical behavior of the rock mass. Rock-mass quality classifications are applied empirically to estimate requirements for underground-excavation support and mechanical properties like the strength and deformation modulus of the rock mass.
room-and-pillar mining	A system of mining in which the rock is mined in rooms separated by pillars of undisturbed rock left for roof support.
rubble	Loose, unconsolidated rock consisting mostly of large, angular rocks intermixed with a small amount of soil or earthy material.
rulemaking	Process of formulating specific regulations governing a particular matter.
salt	The common mineral sodium chloride (NaCl) and any impurities in it.
salt creep	See "creep."
sandstone	Variously colored sedimentary rock composed mainly of sandlike quartz grains cemented by lime, silica, or other materials.
saturated zone	That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.
scabland	An elevated area, underlain by flat-lying basalt flows, with a thin soil cover and sparse vegetation that is crossed by coulees.
scaling	The removal of loose rock from a newly blasted wall or roof.
scanning-transmission electron microscope	A type of electron microscope that scans with an extremely narrow beam of electrons transmitted through the sample; the detection apparatus produces an image whose brightness depends on the atomic number of the sample.
scarification	The process of breaking up and loosening the surface of a material.
scenario	A particular chain of hypothetical circumstances often used in performance analysis to model possible events.
scenario analysis	Analytical process that attempts to quantify the probabilities and consequences of a postulated sequence of events.

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scoria	Vesicular, cindery crust on the surface of andesite or basaltic lava, whose vesicular nature is due to the escape of volcanic gases before solidification.
scouring	Erosion, especially by moving water.
screening	The process of evaluating an area on the basis of criteria or guidelines to identify places that best fulfill the criteria or guidelines.
seal	An engineered barrier to prevent radionuclide migration or the intrusion of undesirable substances.
secondary compression	The reduction in volume of sediments under constant pressure that results from changes in the internal structure of the sediments.
second-order fold	A fold that occurs on the limbs or in the closure of a larger fold. Also referred to as a parasitic fold. (See also "first-order fold.")
secondary sector	The sectors of the economy that serve local residents and businesses. (See "primary sector.")
sedimentary rock	Rock formed of sediment, especially (a) clastic rocks (e.g., conglomerates, sandstone, and shales) formed of fragments of other rock transported from their sources and deposited in water and (b) rocks formed by precipitation from solution (e.g., rock salt and gypsum) or from the secretions of organisms (e.g., most limestones).
seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
seismic reflection line	A line on the earth's surface along which a seismic reflection survey is conducted.
seismic reflection survey	A survey based on measurement of the travel times of waves that originate from an artificially produced disturbance and are reflected back to the surface at nearly vertical incidence from boundaries separating media of different elastic-wave velocities.
seismic refraction survey	A survey based on the measurement of the travel times of seismic waves that have moved nearly parallel to the bedding in high-velocity layers.
seismic survey	Seismic data gathered from an area.
seismicity	The occurrence of earthquakes or the spatial distribution of earthquake activity. Also the phenomenon of earth movement.

seismometer An instrument that receives seismic impulses and converts them into electrical voltage or otherwise makes them evident. Also known as a geophone.

shaft With regard to a geologic repository, the penetration of the natural isolation barrier to provide access to subsurface facility; it is usually of limited cross-sectional area compared to its depth. A more common definition is a manmade hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine or excavation. The difference between a shaft and a borehole is primarily in size and use.

shaft liner A structural lining usually made of steel, concrete, or timber that provides safe rock support and aids in preventing ground water from entering the shaft.

shaft pillar An undisturbed buffer zone surrounding a shaft of sufficient area, so that any possible subsidence in nearby mined areas will not disturb the integrity of the shaft facility.

shaft seal system The devices, mechanisms, or materials used or emplaced between the shaft liner and the rock wall during operation or shaft closure to retard the flow of liquid or gas.

shaft station A horizontally excavated opening of a shaft at a desired depth.

shale A fine-grained detrital sedimentary rock formed by the compaction of clay, silt, or mud.

shear (1) A strain that causes contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. (2) Surfaces and zones of failure by shear or surfaces along which differential movement has taken place.

shear resistance The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called "cohesion." Also called "shear strength."

shear zone A tabular zone of rock that has been crushed and brecciated by many parallel fractures due to shear strain.

sheave A large, pulley-type wheel at the top of the headframe that carries the hoist rope.

shield rocks Areas of exposed basement rocks in a craton commonly with a very gently convex surface, surrounded by sediment-covered platforms.

shielding — The material interposed between a source of radiation and personnel to protect against radiation exposure; commonly used shielding materials are concrete, water, and lead.

shipping cask — A large, heavily shielded vessel for transporting fuel assemblies and radioactive waste. The cask provides physical protection to the contents and radiation protection to its surroundings. Radioactive waste is transported to the repository in shipping casks.

shotcrete — Cement-based compounds sprayed onto mine surfaces to prevent erosion by air and moisture and onto rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and decrepitation.

shrub-steppe — Distinguished from a true steppe by the presence of forbes, shrubs, and a few trees in an extensive grassland area. Generally not as dry as a steppe.

significant source of ground water — As defined in 40 CFR Part 191, an aquifer that (1) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids, (2) is within 770 meters (2,500 feet) of the land surface, (3) has a transmissivity greater than 3×10^{-5} square meter per second (200 gallons per foot per day), provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 1×10^{-6} meter per second (2 gallons per square foot per day), and (4) is capable of continuously yielding at least 1,600 liters per hour (10,000 gallons per day) to a pumped or flowing well for a period of at least a year; or an aquifer that provides the primary source of water for a community water system.

silica — A chemically resistant oxide of silicon (SiO_2).

silicification — The introduction of, or replacement by, silica, generally resulting in the formation of fine-grained quartz, chalcedony, or opal, which may fill pores and replace existing minerals.

sill (geologic) — A tabular igneous intrusion that parallels the planar structure of the surrounding rock.

silt — A sedimentary material consisting of five mineral particles intermediate in size between sand and clay.

siltstone — Stone composed of hardened stone.

sinkhole — An opening at the earth's surface caused by the collapse of rock above a solution zone where ground water has moved along a joint or fracture system and has washed out or dissolved underlying material, such as limestone.

site	A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.
site characterization	Activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.
siting	All of the exploration, testing, evaluation, and decisionmaking associated with site screening, site nomination, site recommendation, and site approval for characterization or repository development.
siting guidelines	General guidelines for siting geologic repositories; issued by the Department of Energy as 10 CFR Part 960.
slabbing	A stress-induced failure mechanism of the rock around an excavation.
slash	A mining technique in which a large-diameter drilled hole is enlarged by using the drill-and-blast method.
sleeve	As related to waste package, a metallic or nonmetallic liner that may be located in the emplacement hole to aid in emplacement and possible retrieval of the waste.
slickensides	Polished and smoothly striated surfaces that result from friction along a fault plane.
slip	The relative displacement of formerly adjacent points on opposite sides of a fault, measured in the fault surface.
slough	Fragments of rock material from the wall of a borehole that are washed out of the hole with the return pipeline.
sloughing	The falling of loosened rock from the roof or walls of and underground excavation.
slump (geologic)	The downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends.
slurry	A fluid mixture of water and finely divided material.

smectite — A group of expanding-lattice clay minerals. These minerals are common in soils, sedimentary rocks, and some mineral deposits and are characterized by swelling in water and extreme colloidal behavior.

solubility — The amount of substance (i.e., an element or compound) that can be dissolved in a given amount of solvent.

solute — A substance dissolved in another substance, usually the component of a solution present in the lesser amount.

sonic log — A geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects lithologic changes.

sorption — The binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. Here "sorption" is used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by chemical or physical forces.

sorptive capacity — The measure of a material's ability to sorb specific constituents from a liquid as it passes through the material.

source term — The types and amounts of radionuclides that make up the source of a potential release of radioactivity.

specific activity — The measure of radioactivity as a function of mass. The unit of specific activity is curie per gram.

specification — A concise statement of a set of requirements prescribing materials, dimensions, or workmanship for something to be built or manufactured.

specific heat — The quantity of heat necessary to raise the temperature of 1 gram of a given substance 1 degree Celsius.

specific yield — The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.

spent fuel — Nuclear fuel that has been removed from a reactor after irradiation and has not been reprocessed to recover uranium and plutonium.

spherulitic — Said of a rock composed of numerous rounded or spherical masses of needlelike crystals, radiating from a central point.

spiracle	A fume or vapor vent in a lava flow, formed by a gaseous explosion in lava that is still fluid, probably due to generation of steam from underlying wet material.
spoils	The debris or waste material from a mine. The rock and other natural materials brought up to the surface during mining. Also called "mined materials" or "mined rock."
stability, repository	The condition resulting from the nature and rates of natural processes affecting the site during the recent geologic past and the expectation that they will be relatively slow and will not significantly change during the next 10,000 years or jeopardize the isolation of the waste. As defined in 10 CFR Part 60, the nature and rates of natural processes (e.g., erosion and faulting) have been and are projected to be such that their effects will not jeopardize the isolation of the waste.
stability of rock structure	The capability of an opening at depth to retain its original shape for a length of time. Stability is related to the quality of the rock mass around the opening, including slabbing and fracture.
standard metropolitan statistical area (SMSA)	One or more contiguous counties containing at least one city of 50,000 inhabitants or more. Additional counties have to meet criteria related to metropolitan character and socioeconomic integration with the central city.
steel sets	Support beams used in mine roofs and walls.
steppe	An extensive treeless grassland area that is developing in the semiarid midlatitudes of southeastern Europe and Asia. Also used to describe similar areas in other parts of the world.
stochastic model	A model whose inputs are uncertain and whose outputs are therefore also uncertain and must be described by probability distributions.
storage coefficient	The volume of water an aquifer releases from, or takes into storage, per unit surface area of the aquifer and per unit change in head.
storativity	The volume of water released from storage in a vertical column of 1 square foot when the water table or other piezometric surface declines 1 foot. In an undefined aquifer, it is approximately equal to the specific yield.
strain	(1) Change in the shape or volume of a body as a result of stress. (2) A change in the relative configuration of the particles of a substance.
stratigraphic setting	The characteristics of the rock layers or other units in the geologic environment.

stratigraphy	The branch of geology that deals with the definition and interpretation of the rock strata, the conditions of their formation, character, arrangement, sequence, age, distribution, and especially their correlation by the use of fossils and other means of identification.
stratum	A single bed or layer of rock regardless of thickness.
stress	In a solid, the force per unit area acting on any surface within it and variously expressed as pounds or tons per square inch, or dynes or kilograms per square centimeter; also, by extension, the external pressure that creates the internal force.
strike	The direction or trend of a structural surface (e.g., a bedding or fault plane) as it intersects the horizontal.
strike-slip fault	A fault in which the net slip is horizontal or parallel to the strike of the fault (see also "dip-slip fault").
stringer	A narrow vein or irregular filament in a rock mass of different material.
student's t test	A standard statistical method used for hypothesis testing and normally used with a sample size of less than 30.
subsidence	Sinking or downward settling of the earth's surface, not restricted in rate, magnitude, or area involved.
subsurface facility	See "underground facility."
sump	A pit or depression serving as a drain or reservoir for liquids.
surface facilities	Repository support facilities in the restricted area.
surface water	Any waters on the surface of the earth, including fresh and salt water, ice, and snow.
surge capacity	The capacity to accommodate radioactive materials by temporary storage at the repository.
syncline	Downfolded strata that form a trough. Beds dip toward the center of a syncline.
system	See "repository system."
system performance	The complete behavior of a repository system in response to the conditions, processes, and events that may affect it.
talus	Loose rock fragments of any size or shape derived from, and lying at, the base of a steep slope.

tectonic	Of, or pertaining to, the forces involved in tectonics or the resulting structures or features.
tectonic activity	Movement of the earth's crust such as uplift and subsidence and the associated folding, faulting, and seismicity.
tectonic breccia	A breccia formed as the result of crustal movements, usually developed in brittle rocks. Slickensides are commonly associated with tectonic breccia, and varying amounts of claylike gouge may be present.
tectonic features	Features such as fault gouge, faulted, and folded rock.
tectonic fractures	Fractures that may or may not have slickensides on their adjoining surfaces and are commonly associated with tectonic breccias. Includes fractures across which no measurable movement has occurred.
tectonic model	A nonnumerical, descriptive theory or concept that incorporates geological, geophysical, and geodetic data into a satisfactory explanation of the evolution of stress and strain in the earth's crust; it can be used to make estimates of future crustal processes.
tectonic province	A region of the earth's crust with relatively consistent structural geologic features.
tectonism	Crustal movement produced by earth forces, such as the formation of plateaus and mountain ranges; the structural behavior of an element of the earth's crust.
tectonics	A branch of geology dealing with the broad architecture of the outer part of the earth; that is, the regional assembling of structural or deformational features, a study of their mutual relations, their origin, and their evolution.
tensile strength	The ability of a material to resist a stress tending to stretch it or to pull it apart.
tephra	A general term for all clastic volcanic materials that are ejected during an eruption and transported through the air.
Tertiary	The earlier of the two geologic periods that make up the Cenozoic Era, extending from 65 million to 1.8 million years ago.
thermal conductivity	A measure of the ability of a material to conduct heat.
thermal decrepitation	The shattering of a rock mass or rock sample caused by the heat-induced buildup of excessive pressures in contained fluids.

thermal expansion — The increase in linear dimensions that occurs when materials are heated.

thermal gradient — The rate of change in temperature with distance.

thermal loading — The application of heat to a system, usually measured in watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area.

thermoluminescent dosimeter — A type of radiation measuring device that contains thermoluminescent material that emits light when subjected to heat. The amount of light emitted is directly proportional to the radiation dose absorbed by the chip.

third-order fold — A fold that occurs on the limbs or in the closure of a second-order fold. (See also "second-order fold.")

tholeiitic — A type of basalt characterized by its lack of olivine.

threatened species — Any plant or animal species protected by Public Law 93-205 that is likely to become endangered in the foreseeable future throughout all or a portion of its range.

thrust fault — A fault with a dip of 45 degrees or less in which the hanging wall appears to have moved upward relative to the foot wall.

tiering — Alternating sequences of entablature and colonnade in a basalt flow.

till — An unsorted and unstratified mixture of glacial debris with a wide range of clast sizes.

to the extent practicable — The degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints.

topography — The branch of geology dealing with the configuration of the land surface, including its relief and the position of natural and man-made features. Also used synonymously with "terrain."

tortuosity — The inverse ratio of the length of a rock specimen to the length of the equivalent path of water within it.

tracer testing — A procedure in which a soluble substance (tracer) is added to ground-water at one location and its movement to another location is observed. Tracer testing is a technique by which ground-water flow directions and velocities and other hydrologic properties of rocks can be estimated.

transfer cask — A cask that provides shielding for the waste disposal container as it is transferred from the waste-handling buildings for emplacement underground.

transgressive sea — A sea that has encroached on the land.

transmissivity — The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the thickness of the aquifer.

transport path — A route along which radionuclides could migrate.

transuranic waste — Waste containing more than a specific concentration of alpha-emitting radionuclides (including uranium-233 and its daughter products) of long half-life and high specific radiotoxicity. This concentration is currently defined as more than 100 nanocuries per gram of waste.

transuranics — Elements with an atomic number higher than 92. They do not normally occur in nature and have to be produced artificially from uranium.

trellis drainage — A drainage pattern characterized by parallel main streams intersected at, or nearly at, right angles by their tributaries.

tridymite — A mineral, SiO_2. It is a high-temperature form of quartz and usually occurs as minute, tabular, white or colorless crystals or scales in cavities in acidic volcanic rocks.

trilateration — Land survey based on triangulation in which the sides of the triangle are measured directly with an interferometer.

tritium — A radioactive isotope of hydrogen with two neutrons and one proton in the nucleus.

tubbing — Cast-iron liner plates for shafts, fabricated to specification, that bolt together to give support to rock.

tufa — A sedimentary rock composed of calcium carbonate, formed by evaporation as an incrustation around the mouth of a spring, along a stream, or around a lake.

tuff — A rock formed of compacted volcanic ash and dust.

tuffaceous — Said of sediments containing up to 50 percent tuff.

unconfined aquifer — An aquifer containing ground water that has a water table or upper surface at atmospheric pressure.

unconformity (geologic)	A break or gap in the geologic record, such as an interruption in the normal sequence of deposition of sedimentary rocks, or a break between eroded metamorphic rocks and younger sedimentary strata.
underground facility	The underground structure and the rock required for support, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.
unit of local government	Any borough, city, county, parish, town, township, village, or other general-purpose political subdivision of a State.
unrestricted area	Any area that is not controlled for the protection of individuals from exposure to radiation and radioactive materials.
unsaturated zone	The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or perched-water bodies, the water pressure locally may be greater than atmospheric.
uplift (geologic)	(1) The process that results in the elevation of a portion of the earth's crust. (2) A structurally high area in the crust produced by movements that have raised or upthrust the rocks, as in a dome or an arch.
upwarping	The uplift of a regional area of the earth's crust, usually as a result of the release of isostatic pressure (e.g., the melting of an ice sheet).
urban area	As defined for use in the 1980 census, incorporated and unincorporated places of 2,500 inhabitants or more.
vadose water	Water of the zone of aeration (unsaturated zone). Also known as "suspended water."
vadose zone	The unsaturated region of soil or the zone of aeration between the ground surface and the water table.
validation of computer codes and models	A process whose objective is to ascertain that the code or model indeed reflects the behavior of the real world.
vent system	A group of generally parallel fissures from which lava came to the surface.
verification of computer codes and models	Testing a code with analytical solutions for idealized boundary-value problems. A computer code will be considered verified when it has been shown to solve the boundary-value problems with sufficient accuracy.

very near field	The waste package and the rock within approximately 3 feet of the waste packages emplaced in a repository.
very unlikely releases	Releases of radioactive wastes to the accessible environment that are estimated to have between one chance in 1,000 and one chance in 10,000 of occurring within 10,000 years.
vesicle	A small cavity in an igneous rock, formed by the expansion of a bubble of gas or steam during the solidification of the rock.
vesicle cylinder	A cylindrical zone in a lava, in which there are abundant vesicles, probably formed by the generation of steam from underlying wet material.
vesicle sheets	A planar or near horizontally emplaced zone in a lava in which there are abundant vesicles.
vitrinite reflectance	An index of the amount of light reflected from a polished surface of the vitrain component of coal; it indicates the relative rank of the coal from lignite to anthracite.
vitrophyre	Any porphyritic igneous rock with a glassy groundmass.
volcanic glass	Natural glass produced by the cooling of molten lava or some liquid fraction of molten lava too rapidly to permit crystallization.
volcaniclastic sediment	A deposit dominated by transported fragments of volcanic origin.
volcanism	The processes by which magma and its associated gases rise into the crust and are extruded onto the earth's surface and into the atmosphere.
voucher collection	A collection of dried plant specimens usually mounted and systematically arranged for reference; a piece of supporting evidence.
vug	A cavity, often within a mineral lining of different composition from that of the surrounding rock.
waste	As used in this document, high-level radioactive waste or spent fuel.
waste canister	See "canister."
waste container	See "container."
waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.

waste management	The planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, solidification, packaging, transportation, initial or long-term storage, surveillance, disposal, and isolation.
waste matrix	The material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and ground water. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.
waste package	The waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.
water budget	The quantification of the amount of water entering, moving through, and leaving a flow system; sometimes called "water balance."
water flux	A stream of flowing water; flood or outflow of water.
watershed	A drainage basin.
water table	The water surface in a body of ground water at which the water pressure is atmospheric.
welded tuff	Indurated volcanic ash in which the constituent glassy shards and other fragments have become welded together, apparently while still hot and plastic after deposition. Where the distinction between nonwelded and partly welded tuff is necessary, the boundary should be placed at or close to that point where the deformation of glassy fragments becomes visible. The transition from partly to densely welded tuff is one of progressive loss of pore space accompanied by an increase in the deformation of the shards and pumiceous fragments.
Werner deconvolution method	The solutions obtained in terms of thin magnetic layers by a mathematical process in which the depth points, dip directions, and susceptibility values are automatically calculated from the profile magnetic data.
wind rose	A diagram showing the distribution with direction of the frequency and the speed of the wind.
worst-case analysis	An analysis based on assumptions and input data selected to yield a "worst impact" statement.
x-ray diffraction analysis	Analysis of the crystal structure of materials by passing x-rays through them and registering the diffraction (scattering) image of rays.

xenolith — An inclusion in an igneous rock to which it is not genetically related.

Young's modulus — A modulus of elasticity in tension or compression, involving a change in length.

zeolites — Any of various silicates analogous in composition to the feldspars and occurring as secondary minerals in cavities, along fractures, and on joint planes in basaltic lavas. Occur also as authigenic minerals in sedimentary rocks.

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ACRONYMS AND ABBREVIATIONS

Act	Nuclear Waste Policy Act of 1982
AEC	Atomic Energy Commission
ALARA	as low as is reasonably achievable
ANSI	American National Standards Institute
BLM	Bureau of Land Management (U.S. Department of the Interior)
BWR	boiling-water reactor
CH-TRU	contact-handled transuranic waste
dB	decibel
dBA	decibel (A-weighting network)
DHLW	defense high-level waste
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
FSAR	final safety analysis report
FWS	U.S. Fish and Wildlife Service
HAW	high-activity waste
HEPA	high-efficiency particulate air (filter)
HLW	high-level waste
HMTA	Hazardous Materials Transportation Act
IAEA	International Atomic Energy Agency
ICC	Interstate Commerce Commission

MRS	monitored retrievable storage
MTHM	metric tons of heavy metal
MTU	metric tons of uranium
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission; National Research Council
NTS	Nevada Test Site
OCRWM	Office of Civilian Radioactive Waste Management
PAC	potentially adverse condition
PMF	probable maximum flood
PUREX	plutonium and uranium recovery through extraction
PWR	pressurized-water reactor
SARP	safety analysis report for packaging
SJC-WCD	San Juan County Water Conservation District
SMSA	standard metropolitan statistical area
Supply System	Washington Public Power Supply System
TRU	transuranic (waste)
TWC	Texas Water Commission
USLE	universal soil-loss equation
UTF	underground test facility
UTM	Universal Transverse Mercator
VRM	visual resource management
WHPF	waste handling and packaging facility

WIPP	Waste Isolation Pilot Plant
WNP	Washington Public Power Supply System Nuclear Project
WPPSS	Washington Public Power Supply System
WVHLW	West Valley high-level waste

7 0 1 6 8 1 6 6 5

Appendix A

TRANSPORTATION

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TABLE OF CONTENTS

Page

A.1 INTRODUCTION. A-1

A.2 AGENCIES WITH JURISDICTION OVER THE TRANSPORTATION OF RADIOACTIVE WASTE A-2
A.2.1 Federal jurisdiction A-2
A.2.2 State role A-3

A.3 PARTICIPANTS IN THE SHIPPING PROCESS. A-3

A.4 REGULATIONS RELATED TO NORMAL TRANSPORTATION. A-4

A.5 REGULATIONS RELATED TO MITIGATING THE CONSEQUENCES OF ACCIDENTS . . A-4

A.6 REGULATIONS RELATED TO SAFEGUARDS A-6
A.6.1 Safeguards A-6
A.6.2 Conclusion A-9

A.7 PACKAGINGS. A-9
A.7.1 Packaging design, testing, and analysis. A-9
A.7.2 Types of packaging A-10
A.7.2.1 Spent fuel. A-11
A.7.2.2 Casks for defense high-level waste and West Valley high-level waste. A-11
A.7.2.3 Casks for use from an MRS to the repository. A-16
A.7.3 Possible future developments A-16
A.7.3.1 Mode-specific regulations A-16
A.7.3.2 Overweight truck casks A-17
A.7.3.3 Rod consolidation A-17
A.7.3.4 Advanced handling concepts. A-17
A.7.4 Conclusions. A-17

A.8 POTENTIAL HAZARDS OF TRANSPORTATION A-18
A.8.1 Potential consequences to an individual exposed to a maximum extent. A-18
A.8.1.1 Normal transport. A-18
A.8.1.2 Accidents A-21
A.8.2 Potential consequence to a large population from very severe transportation accidents. A-23
A.8.3 Risk assessment. A-25
A.8.3.1 Outline of method for estimating population risks. A-25
A.8.3.2 Computational models and methods for population risks. A-25
A.8.3.3 Changes to the analytical models and methods for population risks. A-26
A.8.3.4 Transportation scenarios evaluated for risk analysis A-28

TABLE OF CONTENTS (Continued)

Page

A.8.3.5 Assumption about wastes A-30
A.8.3.6 Operational considerations for use in risk analysis A-30
A.8.3.7 Values for factors needed to calculate population risks. A-33
A.8.3.8 Results of population risk analyses A-43
A.8.3.9 Uncertainties A-59

A.9 COST ANALYSIS A-59
A.9.1 Outline of method. A-59
A.9.2 Assumptions. A-59
A.9.3 Models A-60
A.9.4 Cost estimates A-60
A.9.5 Limitations of results A-60

A.10 BARGE TRANSPORT TO REPOSITORIES A-68

A.11 EFFECT OF A SECOND REPOSITORY ON TRANSPORTATION ESTIMATES A-72
A.11.1 Single repository analyses. A-74
A.11.2 Logic supporting the supplementary analysis A-74
A.11.3 Description of supplementary analyses A-75

A.12 CRITERIA FOR APPLYING TRANSPORTATION GUIDELINE. A-75

A.13 COMMON QUESTIONS REGARDING TRANSPORTATION A-82
A.13.1 Prenotification A-82
A.13.2 Emergency response. A-83
A.13.3 Highway routing A-84
A.13.3.1 Highway routing regulations. A-84
A.13.3.2 State and local ordinances. A-85
A.13.4 Railroads A-86
A.13.4.1 Railroad routing A-86
A.13.4.2 Rail regulations A-86
A.13.4.3 Dedicated trains A-88
A.13.5 Insurance coverage for transportation accidents A-88

References for Appendix A A-91

7 0 1 6 8 0 1 6 6 8

LIST OF FIGURES

Figure	Title	Page
A-1	Truck spent-fuel cask	A-13
A-2	Rail/barge spent-fuel cask.	A-14
A-3	DHLW truck cask	A-15
A-4	Reactors west of 100° longitude	A-74
A-5	Analysis of shipping	A-77

7 0 1 6 8 1 6 6 9

LIST OF TABLES

Table	Title	Page
A-1	Reference cask capacities	A-12
A-2	Projected maximum individual exposures from normal transport (truck spent fuel cask)	A-19
A-3	Projected maximum individual exposures from normal transport (rail spent fuel cask)	A-20
A-4	Maximum individual radiation dose estimates (rail cask accident)	A-22
A-5	50-year population dose estimates for rail cask accidents	A-24
A-6	Repository acceptance schedule	A-29
A-7	Facility receipt rates for scenario involving all reactors shipping to an MRS facility	A-31
A-8	Facility receipt rates for scenario involving eastern reactors shipping to an MRS facility	A-32
A-9	Radiological risk factors for reactors to repository/MRS	A-34
A-10	Nonradiological risk factors for reactors to repository/MRS	A-35
A-11	Radiological risk factors for shipments from the MRS facility	A-36
A-12	Non-Radiological risk factors for shipments from the MRS facility	A-37
A-13	Distance per shipment from selected reactors and the MRS facility	A-38
A-14	Distance per shipment from high-level-waste sources	A-39
A-15	Total cask-miles	A-40
A-16	Fraction of travel in population zones from reactors and the MRS facility	A-41
A-17	Fraction of travel in population zones from high-level-waste sources	A-42
A-18	Number of shipments to a repository from each reactor site (authorized system)	A-44
A-19	Number of shipments to an MRS facility from eastern and western reactor sites	A-45
A-20	Summary of cask shipments	A-47
A-21	Summary of the risks of transportation of spent fuel and high-level wastes	A-48
A-22	Summary of the risks of transportation of spent fuel and all wastes	A-49
A-23	Summary of the risks of transportation of spent fuel and all wastes	A-50
A-24	Risks of spent-fuel transportation - authorized system	A-51
A-25	Risks of high-level-waste transportation - authorized system	A-52
A-26	Risks of transporting all wastes - authorized system	A-53

LIST OF TABLES (Continued)

Table	Title	Page
A-27	Transportation risks for the improved-performance system: all fuel to MRS facility, 100-T cask, spent fuel to MRS facility	A-54
A-28	Transportation risks for the improved-performance system: all fuel to MRS facility, 100-T cask, consolidated spent fuel to repository from MRS facility	A-55
A-29	Transportation risks for the improved-performance system: all fuel to MRS facility, 100-T cask, secondary waste only	A-56
A-30	Transportation risks for the improved-performance system: all fuel to MRS facility, 100-T casks, DHLW only	A-57
A-31	Transportation risks for the improved-performance system: all fuel to MRS facility, 100-T cask, total	A-58
A-32	Total transportation cost	A-61
A-33	Costs for transportation from reactors to repository	A-63
A-34	Costs for transportation with an MRS facility	A-64
A-35	Capitol and maintenance costs (million 1985)	A-65
A-36	Total transportation packaging requirements	A-66
A-37	Costs for transporting defense high-level waste and West Valley waste	A-67
A-38	Costs for transporting defense high-level waste and West Valley Waste	A-68
A-39	Reactor sites in eastern United States included in barge study	A-70
A-40	Projected latent cancers for shipments to repositories from reactors with barge access	A-71
A-41	Summary of radiological air-release consequences from spent-fuel barge accidents	A-72
A-42	Summary of radiological water-release consequences for barge accidents	A-72
A-43	Cask miles from reactors to repository sites with and without an MRS facility	A-78
A-44	Variation in cask-miles resulting from the introduction of the second repository	A-78
A-45	Criteria for applying the transportation guideline	A-79

Appendix A

TRANSPORTATION

A.1 INTRODUCTION

This appendix, which is common to all environmental assessments, presents general background information on transportation topics and issues and provides supplementary references to more-detailed sources of information. The discussions throughout the appendix are specific to the spent-fuel and high-level-waste shipments that will be made to a repository.* The agencies responsible for the regulation of radioactive-material transportation are identified, and their regulations or requirements are reviewed. The shipping casks and cask concepts that will be developed in compliance with the regulatory framework are also described. These topics are discussed in the context of protecting public health and safety against the potential hazards associated with normal transportation, accidents, and sabotage. In addition, the bases for, and the methods of, evaluating the relative transportation risk and cost for each of the sites nominated as suitable for characterization are briefly considered. Separate sections are included to consider the use of barges as an alternative mode of transportation, and to discuss how the consideration of a second repository would affect the results of a single-repository analysis. Also included is a section that describes the criteria developed to aid in the application of the siting guideline on transportation. Finally, several of the major transportation issues (routing, prenotification, emergency reponse, and liability) that have been raised by the public are discussed.

For purposes of discussion in this appendix, the following terms unique to the vocabulary of transportation are defined:

- Packaging (cask) - the assembly of components, excluding contents, that shields and contains the radioactive contents. Packaging may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks.

- Package - packaging together with its contents as presented for transportation. This term is distinct from "waste package," which denotes the contents of the waste-emplacement hole in the repository.

- Normal transportation - all conditions of transportation except those that result from accidents and sabotage.

Additional lists of transportation terms that may be of interest are found in 49 CFR 171.8, 49 CFR 173.403, and 10 CFR 71.4.

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* For convenience and brevity, the term "radioactive waste" or simply "waste" is often used to mean spent fuel or all of the waste to be accepted by the repository.

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A.2 AGENCIES WITH JURISDICTION OVER THE TRANSPORTATION OF RADIOACTIVE WASTE

A.2.1 FEDERAL JURISDICTION

The number of Federal organizations involved in the regulation of radioactive-waste transport is large, and their responsibilities and authorities are interrelated. However, only the functions of the U.S. Department of Transportation (DOT), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE) are discussed here because of their predominance in radioactive-materials transport. More-detailed information and information about organizations not mentioned can be found in reports by Wolff (1984) and the NRC (1977).

The DOT has regulatory responsibility for safety in the transportation of all hazardous materials, including radioactive materials. This responsibility extends to all modes of transportation that would be considered for shipping waste to the repository. Under its establishing legislation, the Department of Transportation Act of 1966, the DOT is responsible for encouraging cooperation among Federal, State, and local governments, carriers, shippers, labor, and other interested parties to achieve national transportation objectives. The regulatory and enforcement authority of the DOT over the shipments of radioactive material that are in, or may affect, interstate commerce was extended by the Hazardous Materials Transportation Act (HMTA) of 1974 to include, but not be limited to, the packaging of specified types and quantities of radioactive materials, handling, labeling, placarding, routing, and driver training.

The NRC provides supplementary regulations related to the transportation of radioactive material. Under the Atomic Energy Act of 1954, as amended, the NRC has responsibility for safety in the possession, use, and transfer (including transportation) of by-product, source, and special nuclear materials. The NRC licenses commercial entities that possess and use these materials. It also promulgates regulations applicable to NRC-licensees regarding the packagings of specified quantities of highly radioactive materials, prenotification of shipments, and the physical protection of spent-fuel shipments from acts of theft and sabotage. The DOT, by agreement with the NRC, accepts the NRC standards of 10 CFR Part 71 for packagings. This agreement has been formalized in a memorandum of understanding between the two agencies (Federal Register, Vol. 44, p. 38690, July 2, 1979). These standards are now in general agreement with international regulations. To aid in enforcement, the NRC requires its licensees to comply with DOT regulations when those entities are not otherwise subject to the DOT regulations.

The shipments of radioactive material conducted by the DOE are also subject to DOT regulations. Authority has been granted to the DOE by DOT regulations (49 CFR 173.7) to approve and certify packagings made by or under the direction of the DOE, as long as the evaluation, approval, and certification are against packaging standards equivalent to those specified in the NRC regulations in 10 CFR Part 71. Although the DOE will take title to all shipments of spent fuel and will be the shipper of record with the authority to use DOE-certified packages, a procedural agreement (Federal Register, Vol. 48, p. 51875, November 14, 1983) has been signed between the

NRC and the DOE; it provides that the DOE will, while making radioactive-waste shipments from NRC-licensed facilities to facilities established under the Nuclear Waste Policy Act (the Act), use NRC-certified packages. The agreement is currently limited to matters of health and safety incident to packaging.

The Act also restates the requirement that the DOE must comply with DOT regulations. A memorandum of understanding between the DOE and the DOT delineates the respective responsibilities and establishes common planning assumptions that the DOE and the DOT will observe in the implementation of transportation requirements under the Act (Federal Register, Vol. 40, p. 47421, November 18, 1985).

A.2.2 ROLE OF STATES

The States also have an important role in regulating the transportation of radioactive materials. Some States have adopted DOT regulations and apply them to intrastate shipments as well as interstate shipments. A particularly important role of the State under DOT regulations is that of designating preferred highway routes for shipments of the type of radioactive materials that would be shipped under the Act (DOT, 1984). A more complete discussion of the States' roles in highway routing is presented in Section A.13.3.1.

A.3 PARTICIPANTS IN THE SHIPPING PROCESS

Three major participants in the shipping process are subject to existing Federal regulations: the shipper, the carrier, and the receiver. The shipper is responsible for the transfer of the radioactive material even though the material may be physically transported by someone else. The shipper must identify the contents of the package, inform the carrier (the actual transporter) of the contents of the package, and must notify the States through which a shipment will pass. Also, the shipper must perform contamination and radiation-level surveys, prepare shipping papers, and certify on the shipping papers that the package is properly prepared. The shipper is instrumental in ensuring the safety of the shipment. The carrier must placard the vehicle, provide any training that may be required, prepare a route plan, and ensure that prescribed routes are followed. The receiver generally acts to support the shipper by inspecting shipments on arrival and by preparing the transportation vehicle for the return trip, ensuring that contamination levels, if any, are below regulatory limits.

The shipping participants under the Act are expected to be the DOE as the shipper of record (the responsibility of separate offices within the DOE for shipments of defense waste to a repository has not been decided upon yet), commercial transporters as the carriers, and the DOE's Office of Civilian Radioactive Waste Management (OCRWM) as the receiver.

A.4 REGULATIONS RELATED TO NORMAL TRANSPORTATION

The hazards of radioactive-material transportation under normal conditions are minimized by existing regulations. All radioactive materials emit penetrating radiation of varying strength and penetrating power, and shielding is provided in the packaging to reduce this radiation to low levels. Many administrative regulations have been developed to (1) identify packages that contain radioactive material and (2) limit exposures to low levels.

A package must be properly prepared and have proper markings and labels. In addition, a vehicle carrying radioactive material of the type that would be shipped to a repository must be placarded for further identification. A tamper seal is used to show that a shipment has not been opened by unauthorized personnel. Furthermore, the shipper must prepare shipping papers and driver instructions that identify the materials being transported and provide appropriate instructions for shipping.

Limits are prescribed for both temperature and radiation-dose rates. The accessible surface temperatures of packages may not exceed 82°C (180°F). Most likely, the casks for the DOE's waste-management program will be designed to ensure that the radiation-dose rates for shipments to a repository will be at the regulatory limit of 10 mrem/hr at 2 meters (6.6 feet) from the external surface of the vehicle or trailer. A radiation dose equivalent to 1 year's exposure to natural background radiation would be received in 10 to 15 hours if a person were to stand at the 2-meter (6.6-foot) distance. Although these exposures are low, the labels and placards are intended to alert the public and to prevent prolonged inadvertent contact with a shipping vehicle or package.

Since loose radioactive material may adhere to the external surface of the package or the vehicle, external contamination is also monitored to ensure that it does not reach harmful levels.

There are many other regulations that have an important effect on the safety and efficiency of radioactive-material shipments. These regulations include requirements for driver training and qualification, notifications, and safeguards. A good review of current DOT regulations can be found in a recent DOT report (DOT, 1983b). The regulations are found in 49 CFR Parts 100-179. NRC regulations are found in 10 CFR Part 71 and Part 73.

A.5 REGULATIONS RELATED TO MITIGATING THE CONSEQUENCES OF ACCIDENTS

During the period from 1971 to 1981, over 1,500 truck and rail shipments of spent fuel were completed (Newman, 1985), and only 4 accidents occurred (Emerson and McClure, 1983). Two of these accidents occurred when the casks were empty. None of the casks released radioactive material.

The packaging is the primary means of protection in the event of an accident. The stringency of regulations for packagings is related to the hazard of the radioactive contents if they were to be dispersed during an accident. For the radioactive materials that will be shipped to a repository, packagings must be designed to preclude significant releases even under severe accident conditions. Under the conditions of the vast majority of accidents, packaging design will preclude entirely the release of material. This section discusses design criteria in regulations, while Section A.7 discusses proposed designs of packagings for shipments to a repository.

Among other requirements, packagings for shipments to a repository will have to survive the testing conditions identified in 10 CFR Part 71. These testing conditions have been estimated to be more severe than those encountered in at least 99.9 percent of all transportation accidents (McClure, 1981). By demonstrating the capability to survive such severe conditions, a packaging can be expected to completely contain its contents during an accident, and this has been the experience to date.

The specific tests to which the same packaging is subjected are as follows:

1. A free drop of 9 meters (30 feet) onto an unyielding target.

2. A free drop of 1 meter (40 inches) onto a puncture probe of a specified size.

3. An exposure to an engulfing thermal environment of 800°C (1,475°F) for 30 minutes.

4. An immersion under 0.9 meter (3 feet) of water for 8 hours.

5. An immersion under 15 meters (50 feet) of water for 8 hours (an undamaged packaging may be used for this test).

Information about the basis for these specific tests can be found in a report published by the International Atomic Energy Agency (IAEA, 1973).

In the first four tests, the same package must be tested in sequence and in the orientation expected to cause the most damage. The extent to which a cask survives such a test is measured by prescribed allowable leak rates and prescribed maximum exposure rates at specified distances from the surface of the package. Regulations, detailed descriptions, leak rates, and survival criteria can be found in 10 CFR 71.51(a)(2), in DOE Order 5480.1, in an NRC regulatory guide (NRC, 1975), and in a standard issued by the American National Standards Institute (ANSI, 1977).

Once a package design to be used for shipments to a repository (not all radioactive-material packages must survive accident conditions) has been demonstrated to survive the rigorous accident conditions as well as many other criteria, a certificate of compliance is issued. The certificate specifies the operating conditions under which the package may be used.

Both the regulations and the certificates can be modified to include experience that relates to the performance of packages. For example, in a recent occurrence (Klingensmith et al., 1980), damaged spent fuel became oxidized during shipment, and a serious contamination problem resulted during unloading. As a result, the NRC has modified the certificates of compliance of currently certified spent-fuel casks to require that they be operated with inert atmospheres in the cask cavity. By using an inert gas in the cask cavity, the potential for fuel oxidation is substantially reduced.

Since the transportation packaging can be relied on for protecting the public during an accident, shipments can be allowed to occur in general commerce. Consequently, relatively few Federal regulations for vehicles are imposed on the carriers of radioactive materials (excluding physical protection requirements) beyond those required for the carrier of any hazardous material. Vehicle-safety conditions are addressed by other Federal and State regulations that are not specific to vehicles carrying radioactive material. For example, truck safety is governed by the Bureau of Motor Carrier Safety (49 CFR Parts 390-398), which imposes vehicle-safety and driver standards on all interstate truck carriers. Along with other functions, the Bureau conducts unannounced roadside inspections of truck carriers and drivers. During an inspection, the weight and a variety of safety considerations, including vehicle lights and brakes and driver documents, are checked. For rail shipments, similar inspection criteria and safety requirements have been promulgated by the Federal Railroad Administration in 49 CFR Parts 209-236. Regulations related to hazardous materials transportation by rail are discussed in Section A.13.4.2.

A.6 REGULATIONS RELATED TO SAFEGUARDS

An issue that has caused concern about the public risk due to radioactive-material transportation is the hazard posed by the sabotage of a radioactive-material shipment. One postulated scenario is the destruction of a loaded cask with well-placed explosives. Such an attack would be of particular concern if it were conducted in a densely populated area.

A.6.1 SAFEGUARDS

In June 1979, the NRC published regulations for the protection of commercial-spent-fuel shipments. In 1980, after reviewing public comments and assessing its own experience in administering these regulations, the NRC published amendments to the rule. The NRC further amended the rule in 1982 to include State prenotification requirements. The amended rule is currently in effect as 10 CFR 73.37(a)-(f). These regulations were promulgated to address the issue of safeguarding spent-fuel shipments against acts of terrorism and sabotage, including the possible hijacking and subsequent sabotage of such shipments. Known as physical protection or "safeguard" regulations, these security rules are distinguished from other regulations published by the NRC and other Federal agencies that deal with issues of safety affecting the environment and public health. The safeguard regulations reflected analyses conducted in the mid 1970s. In particular, an NRC-sponsored study (DuCharme et al., 1978) suggested that the sabotage of spent-fuel shipments had the potential for producing serious radiological consequences in areas of high population density. The NRC concluded that to protect public health and to minimize danger to life and property, it was prudent to require that certain safeguard measures be taken to protect spent-fuel shipments until a more precise and scientific analysis could be performed. The study had been concerned with areas of high population density, but, because of the possibility that shipments could be hijacked in low-population areas and subsequently transported to high-population areas, the requirements applied to all shipments regardless of routing.

The NRC stated in the preamble to the rule change that it had intended the original safeguard rules to be in effect until the results of confirmatory research became available and could be analyzed. The NRC and the DOE responded to this need for more testing by sponsoring separate but coordinated experimental programs. Both programs were designed to yield information about the release of radioactive material from a specified reference sabotage event that was defined in terms of the expertise of the saboteurs, the amount of explosives used, the type of charge employed, and the characteristics of the cask. The NRC-sponsored experiments (Schmidt et al., 1982) used model (small-scale) explosives against simulated casks containing irradiated fuel. The program sponsored by the DOE (Sandoval et al., 1983) included one full-scale and several small-scale experiments.

The results of both of these latter studies showed that the likely release of respirable radioactive particles from sabotage and the resulting consequences of individuals breathing such particles are substantially smaller than the estimates made in the previous NRC-sponsored study that had prompted issuance of the original safeguard regulations. That study had predicted several tens of early fatalities and hundreds of latent-cancer fatalities from sabotage in a densely populated urban area of a truck cask containing three fuel assemblies. The subsequent DOE and NRC-sponsored research predicted no early fatalities and fewer than 15 latent-cancer fatalities for the sabotage of a three-assembly cask in a similarly populated area. These latter consequences would occur only under assumptions that are very favorable to the saboteur. Assumptions concerning the age of the spent fuel (i.e., the cooling period), population density, and the lifetime of respirable particles were all postulated at worst- or near-worst-case levels. When such assumptions are changed to more closely resemble typical or normal transportation situations, the resulting consequences are predicted to decline further.

In June 1984, the NRC published proposed amendments to its existing safeguard regulations and solicited public comment. These amendments take into account the results of the experiments sponsored by the NRC and the DOE, but continue to provide for protection against the loss of control over a shipment and the unhindered movement of the shipment by a saboteur. The objectives of both the current rule and the proposed amendments are to--

1. Deny an adversary easy access to shipment-location information.

2. Provide for early detection of hostile moves against, or the loss of control over, a shipment.

3. Provide a means to quickly summon assistance from local law-enforcement authorities.

4. Provide a means to impede the unauthorized movement of a truck shipment into a heavily populated area.

The current NRC safeguard rule requires--

1. Advance notification of each shipment to the NRC.

2. Maintenance of a communications center to continuously monitor the progress of each shipment.

3. Keeping a written log describing the shipment and significant events during the shipment.

4. Advance arrangements with local law-enforcement agencies along the route.

5. Advance route approval by the NRC.

6. Avoiding scheduled intermediate stops to the extent practicable.

7. At least one escort to maintain visual surveillance of the shipment during stops.

8. Shipment escorts to contact the communications center every 2 hours to report the status of the shipment.

9. Capability to immobilize the cab or cargo-carrying portion of a shipment transported by truck.

10. Armed escorts in heavily populated areas.

11. On-board communications equipment.

12. Advance notification to the governor of a State (or the governor's designee) of a shipment to be transported within or through his State, giving the estimated date and time of entry into the State and applicable routing information. This information must not be publicly released until 10 days after the shipment has entered or originated within the State.

All of these requirements will continue to be in effect for shipments of spent nuclear fuel that has been cooled less than 150 days because there is currently not enough information on the consequences of sabotage to this "hotter" fuel to warrant regulatory modifications.

The proposed amendments change the regulations for shipments of spent fuel cooled 150 days or more by eliminating the requirements for--

1. Maintenance of a communications center.
2. Written logs.
3. Advance arrangement with local law-enforcement agencies.
4. Contacts every 2 hours by escorts.
5. Armed escorts in cities.
6. Advance route approval by the NRC.

At present, NRC's safeguard rules apply only to NRC licensees. However, DOT regulations require that DOE-owned spent fuel be shipped under a physical-protection plan that is equivalent to NRC safeguard rules and has been approved by DOT (49 CFR 173.22(c)). DOE Order 1540.1, which covers DOE transportation regulations, is being revised and will include physical protection procedures that essentially parallel the physical-protection procedures proposed by the NRC in 1984.

When shipping commercial waste to a repository, the OCRWM will comply with whatever NRC shipment-protection requirements are in force at the time. The NRC safeguard requirements at present are limited to spent-fuel shipments. The OCRWM will work with the NRC to establish the need for, and the function of, safeguard requirements for the other radioactive waste that could be shipped under the Act.

A.6.2 CONCLUSION

Though transportation packagings have not been specifically designed to mitigate the consequences of a sabotage event, they have been shown experimentally to limit to low levels the potential adverse health consequences to the public. Predictions based on releases experimentally determined in both DOE and NRC studies indicate that no immediate radiation-induced deaths and a small number of latent-cancer fatalities would be expected even in a very densely populated area (Sandoval et al., 1983). To create the level of hazard encountered in the experiments, such sabotage attempts would have to be performed by trained experts, and precise placement of the explosives in the most vulnerable positions would be necessary.

In order to protect the health and safety of the public, the packaging of shipments made to a repository will be as strong as those used in the experimental studies.

A.7 PACKAGINGS

This section discusses the design and fabrication of transportation packagings, trends in future designs, the designs assumed for the cost and risk analysis, and possible future developments.

A.7.1 PACKAGING DESIGN, TESTING, AND ANALYSIS

Radioactive-material packagings, or casks, are designed and certified to carry specific contents. This is necessary because of the unique thermal, radiological, and criticality characteristics of the contents. Other materials can be carried in the cask only if it can be shown that they present no greater radiological, thermal, or criticality hazards than those of the certified contents. Several cask types will be used for transporting waste to a repository. Generally, the size of the package will be dictated by the mode of transportation.

The type of packaging to be used for shipments to a repository is required to survive the conditions of both normal transportation and accidents. Survival is determined by the extent to which the packaging contains its contents, shields against excessive levels of radiation, and prevents a nuclear chain reaction from occurring even after being subjected to the prescribed hypothetical accident conditions (see Section A.5).

A new packaging is designed through a rigorous process similar to that for other nuclear-related products. If a feasible design is proposed, the design proceeds through an engineering analysis of its survivability when subjected to the testing conditions. Physical engineering tests may be conducted during this stage to support analyses. Proof of survivability under accident conditions is required either through analysis, full-scale or model testing, or a combination of both. Once feasibility and survivability are ensured, a final design is prepared. In the design of packaging used for commerical-waste shipments to a repository, all of this effort will be performed by the cask designer for the DOE under a rigorous quality-assurance program. Once the DOE is certain that the design satisfies all requirements, a safety-analysis report for packaging (SARP) will be submitted to the NRC. This SARP will contain a description of all analyses and will be the means for transmitting all operational and safety information to the reviewer. Once the NRC is convinced that all criteria have been satisfied, it will issue a certificate of compliance.

Since packaging certification can be based on engineering analysis, without actual physical testing, it is important to have confidence that the analytical results closely represent those that might be expected to occur if a package were actually subjected to accident conditions. Several experimental programs, both reduced-scale and full-scale, have been run to produce carefully controlled accident environments that can be directly correlated with analysis (Jefferson and Yoshimura, 1978). The correlations have been reasonably close, and much confidence has been developed in analytical modeling capabilities as a reliable and cost-effective tool to replicate response to accident conditions.

A.7.2 TYPES OF PACKAGING

The analyses presented for transportation in this environmental assessment are based on the representative characteristics of a new family of casks that are expected to be used to transport spent fuel and high-level waste. These casks either are being designed now or will be designed in the future, and more accurately represent the type of packaging that will be used than do existing casks being used to transport commercial spent fuel.

As stated earlier, packagings are designed for specific contents; spent-fuel casks are no exception. The existing casks that are currently in use are designed to shield, dissipate heat, and prevent a nuclear chain reaction in spent fuel that has just come out of a reactor. Because the spent fuel to be shipped to a repository will have been out of the reactor for many years (5 years at a minimum), the existing casks are "overdesigned" for the mission. Although the expected radiation-dose rates would be much lower than those allowed by regulation, the cask payloads are also lower than optimum, thus requiring more shipments. The lower radiological risk per shipment using existing casks would be roughly offset by the increased overall risk that would result from the increased number of required shipments.

The DOE is planning new cask designs that will increase payloads and substantially reduce the number of shipments. Table A-1 presents the cask capacities assumed for performing the consequence and risk analyses in Section A.8. These casks will benefit from past designs, but the application of current technology and analytical tools may allow improvements in design. For example, new-generation casks will probably be designed to be handled entirely remotely and thus will eliminate much routine worker exposure.

A.7.2.1 Spent-fuel casks

Figures A-1 and A-2 show a representative truck cask and a representative rail cask that will be used to transport spent fuel to a repository or to a facility for monitored retrievable storage (MRS) if such a facility is approved by Congress (see Section A.8.3.4). The 100-ton rail cask depicted could also be used for barge transport. The truck cask will be able to accommodate two spent-fuel assemblies from a pressurized-water reactor (PWR) or five assemblies from a boiling-water reactor (BWR). This represents about a doubling of capacity over existing truck casks. The representative truck cask will weigh 21,773 kilograms (48,000 pounds) when empty; when the cask is loaded on the tractor and trailer, the vehicle will weigh less than 36,288 kilograms (80,000 pounds), a weight that will allow it to travel relatively unimpeded by State weight limits for vehicles on the nation's highways. The cask may be constructed of carbon or stainless steel; shielding may be provided by steel, depleted uranium, or lead.

The rail/barge cask will be able to accommodate 14 PWR or 36 BWR assemblies, again representing a doubling of current cask capacity. The concept shown has a stainless-steel body with a sufficient wall thickness to meet all structural and radiation-limit requirements of regulations.

The conceptual designs for both the truck and the rail/barge casks have external impact limiters (shock absorbers designed to reduce the effects of accidents) mounted on the casks, as well as internal impact limiters made of crushable honeycomb material.

A.7.2.2 Casks for defense and commercial high-level waste

An artist's concept of the truck cask for defense high-level waste (DLHW) is shown in Figure A-3. It will be able to carry one 0.6- by 3-meter (2- by 10-foot) canister of vitrified defense waste (and possibly commerical high-level waste from the West Valley Demonstration Project (WVHLW)). When the cask is loaded on the tractor and trailer, the loaded trailer and tractor will weigh less than 36,288 kilograms (80,000 pounds). The cask will be constructed of stainless steel and will have a shielding sleeve of depleted uranium and steel. The cask will have features that allow it to be remotely handled, and the impact limiters will not have to be removed during loading

Table A-1. Reference cask capacities

Origin and destination	Waste type[a]	Container	Capacity[b]
	SPENT FUEL AND SECONDARY WASTE		
From reactors to repository or MRS facility			
Truck	Spent fuel	Unconsolidated assemblies	2/5
Rail	Spent fuel	Unconsolidated assemblies	14/36
From MRS facility to repository, 100-ton casks			
Salt sites	Spent fuel	Disposal container[c]	24/30
Tuff site	Spent fuel	Disposal container[c]	18/42
Basalt site	Spent fuel	Disposal container[c]	24/45
From MRS facility to repository, 150-ton casks			
Salt sites	Spent fuel	Canister[d]	72/150
Tuff site	Spent fuel	Canister[d]	48/98
Basalt site	Spent fuel	Canister[d]	84/171
From MRS facility to all sites			
100-ton casks	Hardware and high-activity low-level waste	Canister[e]	4
150-ton casks	Hardware and high-activity low-level waste	Canister[e]	7
Rail	Contact-handled transuranic waste	Drum	(f)
	HIGH-LEVEL WASTE		
Defense waste			
Truck	Glass HLW	Canister	1
Rail	Glass HLW	Canister	5
Commercial waste[g]			
Truck	Glass HLW	Canister	1
Rail	Glass HLW	Canister	7

[a] PWR = pressurized-water reactor; BWR = boiling-water reactor.
[b] Pairs of numbers show the number of PWR and BWR assemblies, respectively; for example, 2/5 means 2 PWR assemblies or 5 BWR assemblies.
[c] Disposal containers suitable for direct emplacement in a repository. Container sizes are different for each repository host rock.
[d] In thin-wall canisters that would require encapsulation in disposal container at the repository. Canister sizes are different for each repository host rock.
[e] A canister contains five 55-gallon drums.
[f] Thirty-six drums per transport package, two packages per railcar.
[g] High-level waste from the West Valley Demonstration Project.

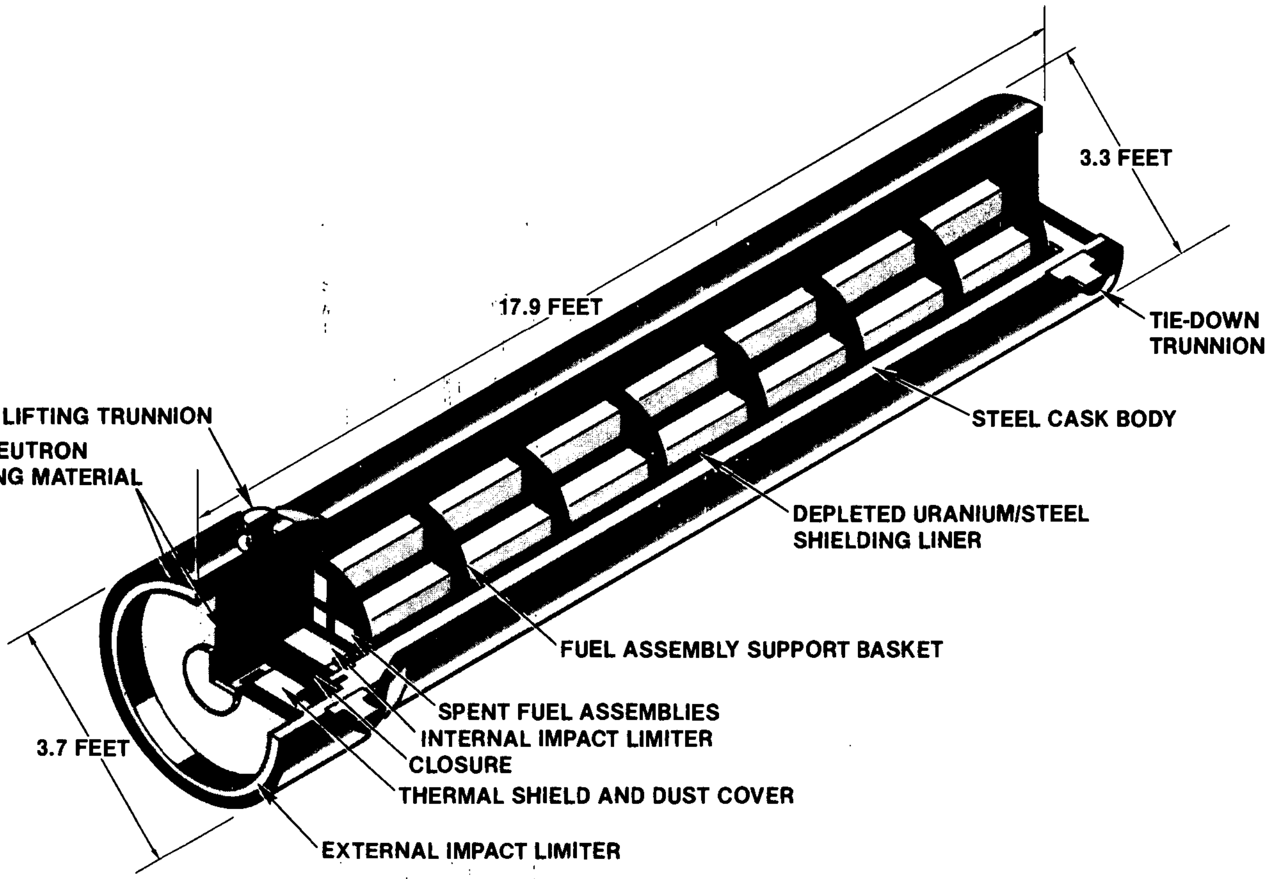

Figure A-1. Truck spent fuel cask.

7 0 1 6 8 1 6 8 4

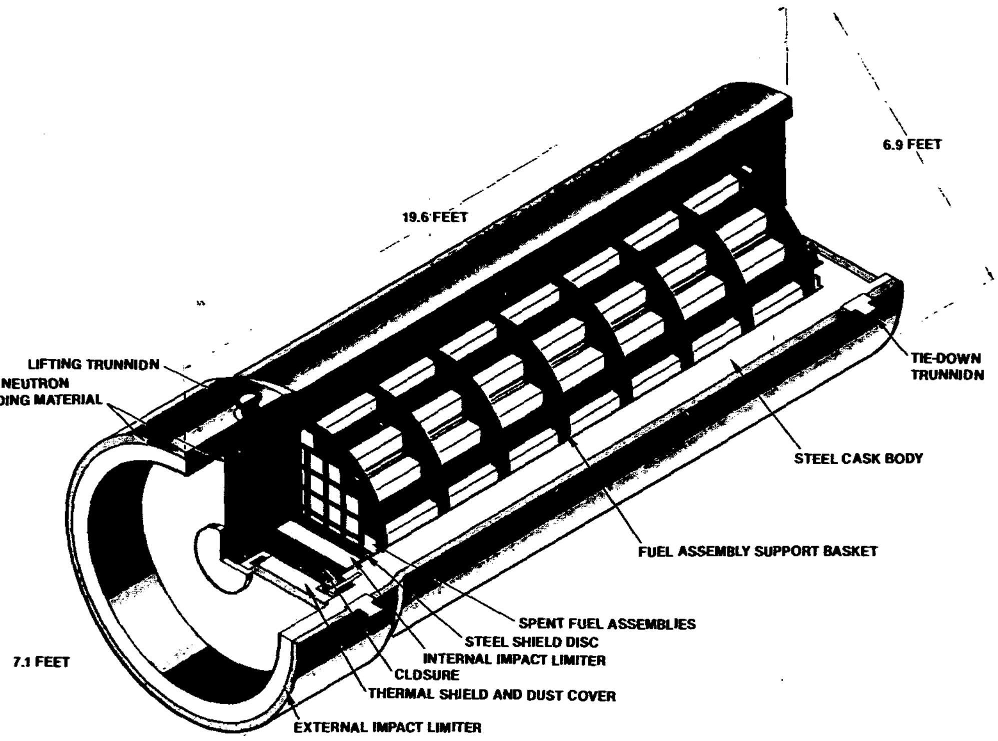

Figure A-2. Rail/barge spent fuel cask.

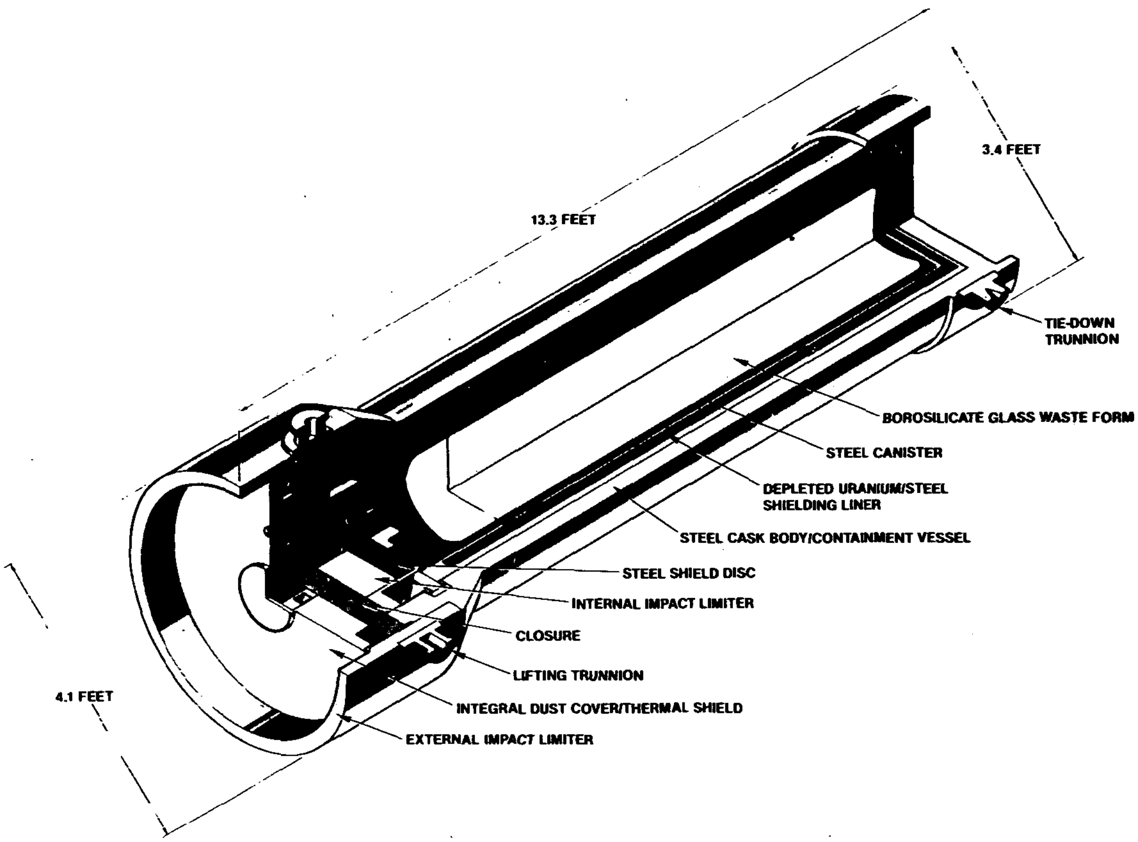

Figure A-3. DHLW truck cask.

and unloading. A rail cask may also be developed; and its capacity is expected to be five canisters of vitrified defense high-level waste (see Table A-1.)

A.7.2.3 Casks for use from an MRS facility to the repository

The DOE's Mission Plan (DOE, 1985) discusses an improved-performance waste-management system that includes a facility for monitored retrievable storage (MRS). Fully integrated into the system, the MRS facility would perform most of the waste-preparation functions now assigned to the repository. In particular, it would consolidate the spent-fuel rods, which are contained in rectangular spent-fuel assemblies, into a tighter circular array, load the consolidated rods into a metal canister, and store the canister until shipment to a repository, where the canisters would be encapsulated in disposal containers and emplaced in the underground disposal rooms. It would also be possible to have the MRS load the consolidated-fuel canisters into disposal containers, which would require no further preparation at the repository.

Casks that would be used in transporting the consolidated spent fuel from the MRS facility to the repository have not yet been designed; however, any design would be certified by the NRC. Scoping analyses have been completed and allow projections of cask capacities to be made. These projections are presented in Table A-1 for casks that weigh 100 and 150 tons. The larger cask may be feasible if an MRS facility is approved by Congress. The cask capacities depend on the host rock of the repository because each host rock is assumed to require a unique canister design and size.

The consolidation of spent-fuel rods at an MRS facility would separate the fuel from the structural components and therefore create another waste type that requires disposal. This secondary waste is separated into three classes: hardware, high-activity low-level waste (HAW), and contact-handled transuranic waste (CH-TRU). It is assumed that the hardware and high-activity waste would be loaded into 55-gallon drums, with five drums loaded into a canister. Packaging capacities for these wastes are given in Table A-1. The transuranic waste would be loaded into 55-gallon drums and shipped in a packaging that is assumed to have a capacity of 36 drums. Two of these packages could be carried by a railcar while only one could be carried by a truck trailer.

A.7.3 POSSIBLE FUTURE DEVELOPMENTS

A.7.3.1 Mode-specific regulations

Even with the safety record of packagings that have been analyzed or tested to survive accident conditions, the NRC is currently reviewing regulations defining accident test conditions in order to assess whether the conditions sufficiently bound those experienced in real accidents. The regulations prescribing accident conditions for transportation are not specific to the mode of transportation, the implicit assumption being that the conditions for all modes are covered by the current standards. Such an assumption has been questioned, and, in response, the NRC is comparing the current standards with actual accident experience for all modes.

A.7.3.2 Overweight truck casks

Highway load restrictions limit the weight of truck casks, which in turn limits cask payloads. In general, these limitations are intended to protect the nation's highway system from damage. Considering the safety objective of minimizing the number of spent-fuel shipments, however, the DOE, in approving designs for future casks, will balance the benefit of reducing shipments against possible road damage caused by overweight vehicles.

Slightly larger truck casks can increase payload capacity, which, in turn, can significantly reduce the number of shipments. The DOE intends to investigate the potential of these larger casks and will consider their use if additional road damage can be minimized. The proposed use of any overweight equipment will be subject to early review and comment by appropriate State officials because the DOE recognizes the State as the permit-issuing authority for shipments requiring overweight or oversize equipment over the nation's highway system.

A.7.3.3 Rod consolidation

Another way to increase the capacities of spent-fuel casks is to consolidate spent-fuel rods in a canister, as mentioned above for the MRS facility. By so doing, cask capacities might be doubled. Preliminary investigations indicate that, in terms of cask design, the principal problems associated with rod consolidation are the increase in weight and the amount of heat that must be dissipated.

A.7.3.4 Advanced handling concepts

Since the number of radioactive-material packages received and handled at a repository will be high, even the low levels of radiation at the surfaces of the packages would be sufficient to cause high total worker exposure. In an attempt to minimize worker exposure, the use of advanced remote-handling equipment, such as robotics, for unloading the packages is being investigated. New shipping casks will be designed to facilitate the cask handling and unloading operations at the repository or MRS facility.

A.7.4 CONCLUSIONS

The design and performance of current packagings are adequate for the specific contents for which they were designed. However, the waste to be transported to a repository would not be efficiently transported in existing casks since it is older and cooler than the contents for which the existing casks were designed (typically spent fuel cooled for 180 days). Therefore, new casks designed for fuel at least 5 years old will be added to the fleet.

These casks will have increased capacities and features that facilitate remote handling. Because these new casks more realistically represent future shipping operations, the expected characteristics of these casks are used in this environmental assessment.

A.8 POTENTIAL HAZARDS OF TRANSPORTATION

This section provides a numerical estimate of the hazard associated with transporting radioactive waste to a repository. In response to numerous comments received on the draft Appendix A, additional emphasis was placed on the potential consequences to an individual, as opposed to a general population. The goal was to answer the frequent question: "What happens to me, if ...?" After explaining the consequences that could be experienced by an individual affected to a credible maximum extent, the consequences are extrapolated to a general population and then finally are combined with accident probabilities to produce an expected value of risk to the public. A separate analysis was performed to consider barge transport, which currently is thought only to provide a potential supplementary role in the transportation system (see to Section A.10). The potential uncertainties inherent in the results presented here are also discussed.

It must be emphasized at this juncture that all analyses are thought to be conservative, and hence the risks they predict are expected to be much greater than the risk that may actually occur.

A.8.1 POTENTIAL CONSEQUENCES TO AN INDIVIDUAL EXPOSED TO THE MAXIMUM EXTENT

The analyses in this section are really ("snapshots in time") where an individual is exposed as a result of a particular set of circumstances that may never happen and would probably never happen twice in exactly the same way or to the same individual. These analyses are specific to a single shipment, and details about shipping schedules and scenarios are deferred until Section A.8.2.

A.8.1.1 Normal transportation

This section presents estimates of credible maximum radiation doses that may be received by a person from selected activities that could result from transportation operations. The activities are not related to accidents but rather could occur during normal operations.

The results in the tables are taken from Sandquist et al. (1985). Sandquist et. al. represent truck and rail casks with a simple analytical model and assume that the dose rates emitted from the casks are at regulatory levels (i.e., at the maximum levels permitted by existing regulations). Table A-2 presents estimates for a truck cask, and Table A-3 is for a rail cask. A number of services or activities are analyzed for each mode.

In order to explain what the results in the tables mean, consider Table A-2 for truck. Under the "truck servicing" category, the table gives the dose

7 0 1 6 8 0 1 6 8 9

Table A-2. Projected maximum individual exposures from normal transport (truck spent-fuel cask)[a]

Description (service or activity)	Mean distance to center of cask (ft)	Maximum exposure time (min)	Dose rate and total dose
Caravan			
Passengers in vehicles traveling in adjacent lanes in the same direction as cask vehicle	35	30	0.04 mrem/min 1 mrem
Traffic obstruction			
Passengers in stopped vehicles in lanes adjacent to the cask vehicle; vehicles have stopped because of traffic obstruction	15	30	0.1 mrem/min 3 mrem
Residents and pedestrians			
Slow transit (because of traffic control through area with pedestrians)	20	6	0.07 mrem/min 0.4 mrem
Truck stop for driver's rest; exposures to residents and passers-by	130	[b]	0.006 mrem/min 3 mrem
Slow transit through area with residents (homes, businesses, etc.)	50	6	0.02 mrem/min 0.1 mrem
Truck servicing			
Refueling (100-gallon capacity)			0.06 mrem/min
One nozzle from one pump	25 (at tank)	40	2 mrem
Two nozzles from one pump	25 (at tank)	20	1 mrem
Load inspection and enforcement	10[c]	12	0.2 mrem/min 2 mrem
Tire change or repair of cask trailer	16[d]	50	0.1 mrem/min 5 mrem
State weight scales	15	2	0.1 mrem/min 0.2 mrem

[a] These exposures should not be multiplied by the expected number of shipments to a repository in an attempt to calculate a worst case because the same individual would not be exposed for every shipment, nor would these circumstances arise during every shipment. An individual residing 100 feet from a transportation route and witnessing every shipment would receive an annual dose of 2 to 8 mrem, depending on the mode of shipment and the cask size.

[b] Assumed to be overnight (8 hours).

[c] Inspection occurs near personnel barrier.

[d] Changed tire is the inside tire nearest cask.

Table A-3. Projected maximum individual exposures from normal transport (rail spent-fuel cask)[a]

Description (service or activity)	Mean distance to center of cask (ft)	Maximum exposure time (min)	Dose rate and total dose
Caravan			
Passengers in rail cars or highway vehicles traveling in same direction and vicinity as cask vehicle	65	10	0.03 mrem/min 0.3 mrem
Traffic obstruction			
Persons in vicinity of cask vehicle stopped or slowed down by rail traffic obstruction	20	25	0.1 mrem/min 2 mrem
Residents and pedestrians			
Slow transit (through station or because of traffic control) through area with pedestrians	25	10	0.07 mrem/min 0.7 mrem
Slow transit through area with residents (homes, businesses, etc.)	70	10	0.02 mrem/min 0.2 mrem
Train stop for crew's personal needs (food, crew change, first aid, etc.)	150	120	0.005 mrem/min 0.7 mrem
Train servicing			
Engine refueling, car changes, train maintenance, etc.	35	120	0.04 mrem/min 5 mrem
Cask inspection and enforcement by train, State, or Federal officials	10	10	0.2 mrem/min 2 mrem
Cask-car coupler inspection or maintenance	30	20	0.07 mrem/min 1 mrem
Axle, wheel, or brake inspection, lubrication, or maintenance on cask car	25	30	0.09 mrem/min 3 mrem

[a] These exposures should not be multipled by the expected number of shipments to a repository in an attempt to calculate a worst case because the same individual would not be exposed for every shipment, nor would these circumstances arise during every shipment. An individual residing 100 feet from a transportation route and witnessing every shipment would receive an annual dose of 2 to 8 mrem, depending on the mode of shipment and the cask size.

delivered to a person changing a tire on the trailer of a truck carrying a loaded spent-fuel cask. To change the tire, that required him to be only 5 meters (16 feet) from the center of the cask. It was further assumed that changing the innermost tire (dual wheels) would take almost a full hour. The dose rate at the location was estimated to be 0.1 millirem (mrem) per minute, a rate that would produce a 5-mrem dose to an individual for the complete service procedure. This dose is about the same as that received on a transcontinental airplane trip. If this person were estimated to change many tires in a year, the DOE may impose administrative controls to minimize the accumulated dose. Such control could be something as simple as requiring temporary lead shields between the cask and the area where the tire was to be changed.

Many of the services or activities analyzed would require administrative controls if they were to happen routinely. Routine occurrences either would not be allowed, or administrative controls would be applied to limit cumulative exposures. These types of activities and services will be more fully analyzed during the preparation of the environmental impact statement. This analysis does highlight the fact that additional controls may be necessary for the large numbers of shipments that will occur under the Act, but it must also be emphasized that the simplified model used by Sandquist et al. (1985) will calculate doses much greater than expected.

A.8.1.2 Accidents

Table A-4 presents the results of an analysis performed by Sandquist et al. (1985) to evaluate the individual dose that may result from three classes of very severe accidents--accidents that would produce conditions more severe than the regulatory test conditions. Accidents of this severity are not likely to occur during shipments to a repository.

Each set of results in Table A-4 is for an accident in which there is a release from a rail cask carrying 14 PWR assemblies. The releases are consistent with those assumed in past analyses (Wilmot et al., 1983; Neuhauser et al., 1984) and are based on the release mechanisms defined by Wilmot (1981).

The three accident classes (4, 5, and 6) are taken from Wilmot et al. (1983). These are very severe accidents, all of which would produce conditions greatly exceeding those specified in the NRC regulations. A Class 4 accident would require a very severe impact (i.e., perhaps a 30-meter (100-foot) drop onto a granite slab). This impact would release adhered activation products and may rupture a few spent-fuel rods. A Class 5 accident requires a Class 4 impact with a subsequent very intense fire (a fire longer and hotter than that of the regulatory test). A Class 6 accident requires a Class 4 impact and an even hotter fire than Class 5. A Class 6 accident would result in the severe oxidation of ruptured fuel rods. These accidents are extremely unlikely; they are estimated to occur once in a million vehicle accidents.

The maximum dose received by an individual in the most severe accident is about 10,000 mrem; it would be incurred by a person standing about 70 meters (230 feet) from the scene of the accident. Most of the dose comes from

7 0 1 6 8 1 6 9 2

Table A-4. Estimated maximum individual radiation dose for rail-cask accidents

Accident class[c]	Dose (mrem)[a,b] Inhalation	Plume gamma	Ground gamma	Dust inhalation	Total
4	180	11	12	0.0001	200
5	6,100	71	91	0.004	6,300
6	9,000	550	710	0.0006	10,300

[a] Maximum individual dose occurs about 70 meters (230 feet) downwind of the release point.

[b] Values reported as the effective whole-body dose.

[c] Accident class as defined by Wilmot et al. (1983). Class 6 is the most severe, but all classes have probabilities of less than 1 in a million accidents.

inhaling radionuclides from the plume. The dose itself would occur over decades and would come from radionuclides retained within the body. Even if all of the dose were received during a short ("acute exposure") period, the individual would show no symptoms nor have his life threatened. An "acute" dose of about 50,000 mrem would be required before any symptoms would be observable; a dose of more than 450,000 mrem would be required before the chance of dying within 30 days is 50-50 (NCRP, 1962).

The doses calculated can be greater or smaller, depending on the circumstances; however, the analyses made no attempt to account for the mitigating measures that would immediately be exercised after an accident. Even such simple measures as staying indoors could easily reduce the doses by tenfold or more. By carefully tracking the release of material as it is dispersed by the wind, such advisories can be made.

The dose received by a firefighter was calculated for an accident even if no radioactive material was released. If the firefighter spent an hour at the scene of the accident, he would receive a dose of up to 24 mrem. A description of this analysis is also given by Sandquist et al. (1985). If a firefighter was responding to an accident in which there was a release and did not use breathing protection, he could be expected to receive a dose of about 10,000 mrem, as described above for the maximumally exposed individual. With breathing protection, the dose could easily be reduced to less than 1,000 mrem.

A.8.2 CONSEQUENCES TO A LARGE POPULATION FROM VERY SEVERE TRANSPORTATION ACCIDENTS

In this section, some doses are calculated for a large population, not just for a single individual as in Section A.8.1. The accidents analyzed are very unlikely, on the order of 1 in a million accidents or less.

Two scenarios are postulated: (1) an accident where material is released during an accident, dispersed, and deposited on the ground and (2) an accident where the radionuclides released are deposited in a reservoir that is used for many purposes, including drinking water. The three most-severe accident classes defined by Wilmot et. al. (1983) are considered, as described in Section A.8.1.2. Three exposure pathways are considered: inhalation, cloudshine, and groundshine. A fourth, the inhalation of resuspended dust, was found to be unimportant in comparison with the other three. As shown in Table A-5, in the most-severe accident in an urban area, 22 latent-cancer fatalities are predicted for the ground-deposition case and 13 for the water-deposition case. These values are based on the assumption that no mitigating administrative control or accident-scene clean-up takes place. Evacuation would reduce these numbers, as would cleaning up the contaminated areas. In the water-deposition case, no credit was taken for the normal settling and filtering processes that take place during water treatment and would certainly be employed after an accident. Details can be found in the report by Sandquist et al. (1985).

Table A-5. Estimated 50-year population dose for rail-cask accidents[A]

Accident consequence	Air release[B]: Urban area[C] Inhalation	Plume gamma	Ground gamma	Total	Rural area[D] Inhalation	Plume gamma	Ground gamma	Total	Water release in urban area[E]
CLASS 4 ACCIDENTS[F]									
Population dose (man-rem)	3	0.33	940	940	0.005	0.0005	1.4	1.4	180
Number of latent-cancer fatalities[G]				0.2				0.0003	0.04
CLASS 5 ACCIDENTS[F]									
Population dose (man-rem)	110	2.2	13,000	13,000	0.2	0.003	21	21	6,900
Number of latent-cancer fatalities[G]				3				0.004	1.4
CLASS 6 ACCIDENTS									
Population dose (man-rem)	150	17	110,000	110,000	0.2	0.03	170	170	63,000
Number of latent-cancer fatalities[G]				22				0.04	13

[A] Estimates based on the assumption that there is no cleanup of deposited radionuclides.

[B] The ground dose is the dose that would be received if each member of the population stayed at the same location for 50 years. The inhalation dose is a 50-year dose commitment from the inhalation of the passing plume. Doses are for the population within 80 kilometers (50 miles) of the release point.

[C] Urban area assumed to have 10,000 people per square mile.

[D] Rural area assumed to have 16 people per square mile.

[E] Population dose from water ingestion. The noble gas krypton-85 is omitted because of its negligible uptake by a surface-water body. Population-dose estimates based on a 100-acre, 1-billion-gallon reservoir that supplies the domestic, agricultural, and industrial needs of 37 million people. No radioactive decay, settling, or filtration is assumed. The water-release accident is much less likely to occur than either of the air-release accidents.

[F] Accident classes as defined by Wilmot et al. (1983).

[G] Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

A.8.3 RISK ASSESSMENT

The preceding section presented the consequences of an accident to a large population. This section examines the expected risk to the public (as a group of individuals) by including not only the consequences but also the probability of the accident. The results depend on shipment logistics and schedules for all shipments. In order to describe the results more clearly and to explain the differences between the results presented in the draft appendix and in this final version, this section briefly describes the computational models and the revisions made in the models, the waste-management scenarios that were analyzed, and assumptions about the waste.

A.8.3.1 Outline of method for estimating population risks

By recognizing similarities and uniformities over a national or large regional scale, simplifying assumptions were made in the risk-assessment calculations. Such simplification is justified because the importance of the results presented is not so much in their absolute values but rather in their relative magnitude when compared among the potential repository sites.

The most important simplification was to create "unit-risk" factors, which represent the risk of transportation for a unit distance of travel in a defined population zone. The use and development of unit-risk factors have been described by Madsen et al. (1983).

Once the unit-risk factors have been obtained for the population zones required (in this analysis, three different population densities were considered), three other factors are needed to evaluate the total risk of transportation to a site: (1) the total distance per trip, (2) the fraction of travel in each of the population zones, and (3) the number of shipments that may occur. Actual distances for representative routes were calculated from each reactor and waste source to the potential repository sites. The number of shipments was calculated from detailed logistics models that are best described in the detailed text of Shay et al. (1985). How the fraction of travel in the various population zones was determined is discussed by Cashwell et al. (1985). It is sufficient here to mention that actual 1980 census data were reduced to population contours, which in turn were overlaid on postulated routes. The distance of travel in each zone was subsequently translated to a fraction of travel.

A.8.3.2 Computational models and methods for estimating population risks

The analytical tools (i.e., the analytical models or codes used in this analysis) have been extensively documented elsewhere, and the interested reader is encouraged to review this documentation for details of model development (AEC, 1972; NRC, 1977; Taylor and Daniel, 1977, 1982; Madsen et al., 1983; Wilmot et al., 1983; Neuhauser et al., 1984). This section identifies the models and shows that they have been developed, used, and verified sufficiently to establish their credibility.

The RADTRAN-II code, which was used to calculate the radiological unit-risk factors, is the product of about 10 years of development. Its precursor was used to produce the environmental assessment used in Interstate Commerce Commission (ICC) hearings concerning the issue of hauling radioactive material in trains dedicated to radioactive material (ICC, 1977). RADTRAN was used to produce documents that are current standards for evaluating the risk of transporting radioactive materials (NRC, 1977, 1983). Furthermore, the code has been used as the basis for other significant risk-assessment tools, including METRAN (Finley et al., 1980), which evaluates the risk of transportation in urban areas, and INTERTRAN (Ericson and Elert, 1983), which is the risk-assessment tool of the International Atomic Energy Agency.

The nonradiological unit-risk factors were calculated from available data collected from actual transportation records (Cashwell et al., 1985).

HIGHWAY (Joy et al., 1982) and INTERLINE (Peterson, 1984) are routing models for highway and rail shipment. Developed over the past several years, they are updated periodically to reflect current road and track conditions and railroad ownership. They are benchmarked against reported mileages and observations of commercial truck and rail firms.

A.8.3.3 Changes in the analytical models and methods for estimating population risks

Many significant improvements have been made in the analytical models and methods since the analyses were by completed by Neuhauser et al. (1984), for the draft environmental assessment. A couple of the modifications have resulted in significant changes in the absolute value of the expected results, and therefore it is important to identify them. The interested reader is encouraged to review the references given.

The most important improvement was made to the railstop model in RADTRAN-II, which calculates the occupational and public dose accumulated as a truck or train is stopped during transit. The primary basis for the change is a survey performed by an expert in railroad operations and documented by Ostmeyer (1985a). The railstop-exposure model can treat both general-freight and "dedicated-train" (see Section A.13.4.3) shipments. The model classifies railstop exposures into two types: employee proximity exposures and general rail-and-nonrail population exposures. The proximity exposures are received by employees who handle waste shipments at railstops. In the case of general-freight shipments, these exposures result from train classifications, car repair, and train inspections. The dedicated-train proximity exposures result from train inspections and car repairs. General rail-and-nonrail exposures are received by railyard employees not handling the shipment and the general population that surrounds the railyard. Unlike crew proximity exposures, which depend on the number of train "handlings," general-population exposures depend on railstop duration.

Another major change to RADTRAN II is the addition of a food-ingestion model. Population doses from food ingestion are estimated by using radionuclide transfer fractions. The model is documented by Ostmeyer et al.

70168 1697

(1985b). Population food exposures are estimated only for accidents that occur in rural areas. However, because of the nature of the model, food-ingestion doses are not limited to the residents of rural areas.

Food transfer fractions were determined for cobalt, cesium, strontium, and plutonium radionuclides. All other radionuclides will make negligible contributions to food-pathway risks for waste-transportation accidents. Each transfer fraction represents the "time-integrated" transfer of the radionuclide through the food-ingestion pathway. Transfer fractions were determined by using both empirical fallout data and systems-analysis models.

The occupational and nonoccupational nonradiological risks for rail accidents were updated to be consistent with the most recent edition of National Transportation Statistics (DOT, 1985). In addition, the calculation of risk associated with dedicated trains was updated to incorporate the appropriate statistical base. Two years of accident data, 1982 and 1983, are cited in this document; to obtain statistics for the analysis performed here, the data for both years were averaged.

For calculating all of the radiological and nonradiological risks associated with incident-free rail transportation, input must be in terms of fatalities per railcar-kilometer and injuries per railcar-kilometer. For general-commerce rail transportation, average occupational and nonoccupational accident-related fatalities are divided by the appropriate average values for railcar-kilometers of Class I freight. The number of injuries are derived from the numbers of fatalities.

However, unlike all radiological risks and incident-free nonradiological pollution risks, which depend on train length, the nonradiological-accident term is dominated by grade-crossing accidents, whose occurrence depends solely on the number of trains rather than the length of trains carrying radioactive waste. Consequently, for dedicated trains only, the unit risk factors are expressed in terms of risk per train rather than risk per railcar. Dedicated trains are assumed for shipments from the MRS facility. Further details are given by Cashwell et al. (1985).

Finally, a method was developed for modifying unit-risk factors to reflect changes in population densities. A brief discussion of this method is presented below.

In the relationships given below, five symbols are used. They are defined as follows:

F_1= A zone- and material-dependent risk factor based on rural, suburban, and urban population densities of 6, 719, and 3,861 persons per square kilometer, respectively.

F_2= Any revision to F_1 desired because of a change in population density.

$\S_1$= One of the population densities (6, 719, or 3,861 persons per square kilometer).

$\S_2$= The altered value of a population density.

a= The fraction of the normal nonoccupational radiological risk contributed by offlink exposures to the general population [a = offlink/(onlink + stops + offlink)].

The following values of the quantity a were used for each mode and population zone:

Mode	Rural	Suburban	Urban
Truck	0.00	0.18	0.07
Train	0.03	0.85	0.47
Dedicated Train	0.23	0.97	0.76

The resultant radiological and nonradiological risk factors are as follows:

Radiological Risks

Normal occupational fatalities	Unchanged
Normal nonoccupational fatalities	$F_2 = F_1[a(\S_2/\S_1) + (1 - a)]$
Accident nonoccupational fatalities	$F_2 = (\S_2/\S_1)F_1$

Nonradiological Risks

Normal nonoccupational fatalities	$F_2 = (\S_2/\S_1)F_1$
Accident occupational fatalities	Unchanged
Accident nonoccupational fatalities	Unchanged
Accident injuries	Unchanged

A.8.3.4 Transportation scenarios evaluated for risk analysis

The DOE has described two different waste-management systems in the Mission Plan (DOE, 1985): an authorized system and an improved-performance system. In the authorized system, spent fuel and defense high-level waste would be shipped directly from the sources (reactors and waste sources) to the repository. In the improved-performance system, a centrally located MRS facility would be used to prepare the spent fuel for disposal in the repository.

The rate at which the repository would accept spent fuel and high-level waste is given in Table A-6 for the authorized system. The high-level waste is assumed to be sent directly to the repository under either plan. The volume of defense waste that is used for this analysis is greater than that presented in the Mission Plan in order not to underestimate the environmental impact of transporting this waste.

Several cases are considered for the improved performance system; they are defined by changes to two inputs: (1) the size of the cask used to transport waste to the repository from the MRS facility and (2) the location to which reactors west of the Rocky Mountains (longitude 100°W) ship their spent fuel. Two cask sizes were considered: 100 and 150 tons. Reactors west

Table A-6. Repository waste-acceptance schedule for the authorized system (metric tons of uranium)

Year	Spent fuel	High-level waste[a, b]			
		Savannah River	INEL[c]	Hanford	West Valley[d]
1998	400				
1999	400				
2000	400				
2001	900				
2002	1,800				
2003	3,000	350		75	20
2004	3,000	350		75	20
2005	3,000	350		75	20
2006	3,000	350		75	20
2007	3,000	350		75	20
2008	3,000	200	300	75	20
2009	3,000	200	300	75	20
2010	3,000	200	300	75	20
2011	3,000	200	300	75	20
2012	3,000	200	300	75	20
2013	3,000	200	300	75	20
2014	3,000	200	300	75	20
2015	3,000	200	300	75	20
2016	3,000	350	300	75	20
2017	3,000	350	300	75	20
2018	3,000	350	300		20
2019	3,000	350	300		20
2020	3,000	350	300		20
2021	3,000	350	300		20
2022	1,100	350	300		20

[a] A canister of high-level waste contains the fission products from the reprocessing of 0.5 MTU of spent fuel.

[b] The values given for high-level waste were developed for use in these EAs. They are believed to be maximum values that would not be exceeded and do not reflect expected values. They do not compare with the values given in the Mission Plan (DOE, 1985).

[c] Idaho National Engineering Laboratory.

[d] Commercial high-level waste from the West Valley Demonstration Project.

of longitude 100°W were assumed to ship either directly to the repository or to the MRS facility. All four combinations were considered. The waste-acceptance rates for the MRS facility and the repository are given in Tables A-7 and A-8 for the two cases involving different destinations for the spent fuel from western reactors.

A.8.3.5 Assumption about wastes

Detailed descriptions of the spent fuel and miscellaneous wastes are given by Cashwell et al. (1985); however, some basic assumptions fundamental to the risk analysis are presented here.

The spent fuel was assumed to be 5 years old if shipped from the reactors and 10 years old if shipped from the MRS facility. In order to bound the consequences, all analyses assume that the composition of the radionuclide release during postulated accidents is derived from a pressurized-water reactor. The fuel burnup was assumed to be 33,000 MWd/MTU. It was assumed that the spent-fuel assemblies have limited amounts of radioactivity ("crud") on their exterior surfaces; this can be knocked loose and readily released to the inside of a cask under accident conditions. Spent fuel shipped from the MRS facility is consolidated and shipped either in a thin-wall repository-specific canister or encapsulated in a container designed specifically for disposal in one of the different repository host rocks. (The repository-specific canisters would be encapsulated in disposal containers at the repository.).

The high-level waste—defense high-level waste from three reprocessing plants and commercial high-level waste from West Valley Demonstration Project—was assumed to have the composition of defense waste from the Savannah River Plant. Therefore, each canister of waste was assumed to contain the inventory resulting from the processing of 0.5 MTU of spent fuel. The waste matrix was assumed to be a glass.

The wastes resulting from fuel consolidation--hardware, high-activity low-level waste, and contact-handled transuranic waste (CH-TRU)--were assumed to be shipped along with consolidated spent fuel to the repository. The hardware contains activation products; the high-activity low-level waste also has significant amounts of fission products; and the contact-handled transuranic waste contains mainly transuranic radionuclides, which pose no particular external radiation hazard. The high-activity low-level waste and the hardware are placed in drums and then five drums are loaded into a canister; the transuranic waste is packed in drums.

A.8.3.6 Operational considerations in risk analysis

Shipments from the reactors and HLW processing plants are made by truck or rail in general-commerce shipments. Cask sizes are limited so that no special restrictions are encountered enroute. Shipments from the MRS facility, however, are made in dedicated trains that haul only the radioactive material being shipped to the repository. The reference dedicated train

Table A-7. Receipt rates for scenario involving all reactors shipping to an MRS facility

	Spent fuel[a] (MTU)		Secondary waste products to repository		
Year	All reactors to MRS	MRS to repository	Hardware (canisters)	High-activity waste (canisters)	CH-TRU[b] (drums)
1996	400				
1997	1,800				
1998	3,000	400	35	33	74
1999	3,000	400	35	33	74
2000	3,000	400	35	33	74
2001	3,000	900	79	74	166
2002	3,000	1,800	158	147	331
2003	3,000	3,000	264	246	552
2004	3,000	3,000	264	246	552
2005	3,000	3,000	264	246	552
2006	3,000	3,000	264	246	552
2007	3,000	3,000	264	246	552
2008	3,000	3,000	264	246	552
2009	3,000	3,000	264	246	552
2010	3,000	3,000	264	246	552
2011	3,000	3,000	264	246	552
2012	3,000	3,000	264	246	552
2013	3,000	3,000	264	246	552
2014	3,000	3,000	264	246	552
2015	3,000	3,000	264	246	552
2016	3,000	3,000	264	246	552
2017	2,800	3,000	264	246	552
2018		3,000	264	246	552
2019		3,000	264	246	552
2020		3,000	264	246	552
2021		3,000	264	246	552
2022		1,100	97	90	202

[a] Spent fuel only; high-level waste is assumed to be shipped directly to a repository in the improved-performance system, bypassing the MRS facility (see Table A-6).

[b] Contact-handled transuranic waste.

70168 01702

Table A-8. Facility receipt rates for scenario involving only eastern reactors shipping to an MRS facility

Year	Spent fuel (MTU): Eastern reactors to MRS	Western reactors to repository	MRS to repository	Secondary waste products to repository: Hardware (canisters)	High-activity waste (canisters)	CH-TRU (drums)
1996	370					
1997	1,665					
1998	2,775	30	370	32	31	68
1999	2,775	30	370	32	31	68
2000	2,775	30	370	32	31	68
2001	2,775	67.5	832.5	73	68	154
2002	2,775	135	1,665	146	228	306
2003	2,775	225	2,775	244	228	511
2004	2,775	225	2,775	244	228	511
2005	2,775	225	2,775	244	228	511
2006	2,775	225	2,775	244	228	511
2007	2,775	225	2,775	244	228	511
2008	2,775	225	2,775	244	228	511
2009	2,775	225	2,775	244	228	511
2010	2,775	225	2,775	244	228	511
2011	2,775	225	2,775	244	228	511
2012	2,775	225	2,775	244	228	511
2013	2,775	225	2,775	244	228	511
2014	2,775	225	2,775	244	228	511
2015	2,775	225	2,775	244	228	511
2016	2,590	225	2,775	244	228	511
2017	2,800	225	2,775	244	228	511
2018		225	2,775	244	228	511
2019		225	2,775	244	228	511
2020		225	2,775	244	228	511
2021		225	2,775	244	228	511
2022		82.5	1,017.5	90	83	187

consists of five spent-fuel casks, two hardware casks, two high-activity-waste casks, and one railcar carrying contact-handled transuranic waste. The dedicated train has different operational characteristics than a general-commerce train, and the analyses reflect those differences.

A.8.3.7 Values for factors needed to calculate population risks

As described in Section A.8.3.1, four factors are needed to assess the population risks from waste transportation: unit risk factors, shipment distances, fractions of travel in various population zones, and the number of shipments.

Tables A-9 through A-12 present all of the unit risk factors used in the analyses made for this environmental assessment. Tables A-9 and A-10 give the factors for shipments that originate at the reactors and the HLW processing plants. The unit risk factors are given for truck and rail shipment and for each population zone. All rail factors are for an individual railcar in general commerce. Table A-9 presents estimates of the radiological risks from normal transportation and accidents. The normal risk is subdivided into occupational and nonoccupational categories. The accident risk is not divided by occupational category because potential exposures for each category are similar (see Section A.8.1.2), and the population density used in the calculations can be considered to include both categories. Table A-10 presents estimates of the nonradiological risk.

Tables A-11 and A-12 contain risk factors for shipments that originate at the MRS facility. Separate factors are given for consolidated-fuel shipments in both the 100- and 150-ton casks and for the secondary wastes that are generated in consolidation. All shipments from the MRS facility were assumed to be by dedicated train, and therefore the unit risk factors are for a complete train (i.e., the factors are on a train-mile, rather than a railcar-mile, basis).

Shipment distances are found in Tables A-13 and A-14. Table A-13 gives the distances from a few chosen reactors in different regions of the United States to the MRS facility and each repository site and from the MRS facility to each repository site. A complete listing of reactors can be found in the report by Cashwell et al. (1985). Table A-14 shows the distances from the HLW sites to the various repository sites. A summary of total shipment distances is given in Table A-15 for each transportation scenario evaluated for the authorized system and the improved-performance system. Distances are given for the cases where shipments are made by all truck or all rail. For two of the scenarios estimates are given for each waste type to provide a perspective on the contribution of each.

The fractions of travel in the various population zones are found in Tables A-16 and A-17 for the selected reactors and the HLW processing sites, respectively. Routes from each source are analyzed to determine the approximate amount of travel in each of the population ones. Further details and all remaining reactor data can be found in the report by Cashwell et al. (1985).

Table A-9. Radiological risk factors for shipments from waste sources to a repository or MRS facility[a]

Mode	Zone	Hazard group	Spent fuel[b]	DHLW[c]	WVHLW[d]
Truck	Rural	Normal occupational fatalities	4.70E-09[e]	4.14E-09	4.14E-09
Truck	Rural	Normal nonoccupational fatalities	2.84E-08	2.54E-08	2.54E-08
Truck	Rural	Accident nonoccupational fatalities	3.10E-13	2.56E-13	1.79E-13
Truck	Suburban	Normal occupational fatalities	1.03E-08	9.10E-09	9.10E-09
Truck	Suburban	Normal nonoccupational fatalities	4.36E-08	3.92E-08	3.92E-08
Truck	Suburban	Accident nonoccupational fatalities	7.46E-10	1.08E-10	7.60E-11
Truck	Urban	Normal occupational fatalities	1.72E-08	1.52E-08	1.52E-08
Truck	Urban	Normal nonoccupational fatalities	5.96E-08	5.36E-08	5.36E-08
Truck	Urban	Accident nonoccupational fatalities	1.22E-09	2.16E-10	1.52E-10
Rail	Rural	Normal occupational fatalities	2.14E-09	2.04E-09	1.03E-09
Rail	Rural	Normal nonoccupational fatalities	1.15E-09	1.03E-09	1.03E-09
Rail	Rural	Accident nonoccupational fatalities	1.34E-12	5.56E-13	5.40E-13
Rail	Suburban	Normal occupational fatalities	2.14E-09	2.04E-09	2.04E-09
Rail	Suburban	Normal nonoccupational fatalities	7.70E-09	6.90E-09	6.90E-09
Rail	Suburban	Accident nonoccupational fatalities	2.78E-09	2.72E-10	2.64E-10
Rail	Urban	Normal occupational fatalities	2.14E-09	2.04E-09	2.04E-09
Rail	Urban	Normal nonoccupational fatalities	2.58E-09	2.32E-09	2.32E-09
Rail	Urban	Accident nonoccupational fatalities	6.72E-09	5.08E-09	4.92E-09

[a] Radiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609. Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

[b] Unit risk factors for general-commerce truck and rail transportation of spent fuel; units are per kilometer for truck and per railcar-kilometer for rail.

[c] Unit risk factors for general-commerce truck and rail transportation of defense high-level wastes; units are per kilometer for truck and per railcar-kilometer for rail.

[d] Unit risk factors for general-commerce truck and rail transportation of commercial high-level waste from West Valley; units are per kilometer for truck and per railcar-kilometer for rail.

[e] 4.70E-09 = 4.7×10^{-9}.

Table A-10. Nonradiological risk factors for shipments from waste sources to a repository or MRS facility[a]

Mode	Zone	Hazard group	Spent-fuel[b]	DFHLW[c]	WVHLW[d]
Truck	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Truck	Rural	Accident occupational fatalities	1.50E-08[e]	1.50E-08	1.50E-08
Truck	Rural	Accident nonoccupational fatalities	5.30E-08	5.30E-08	5.30E-08
Truck	Rural	Accident occupational injuries	2.80E-08	2.80E-08	2.80E-08
Truck	Rural	Accident nonoccupational injuries	8.00E-07	8.00E-07	8.00E-07
Truck	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Truck	Suburban	Accident occupational fatalities	3.70E-09	3.70E-09	3.70E-09
Truck	Suburban	Accident nonoccupational fatalities	1.30E-08	1.30E-08	1.30E-08
Truck	Suburban	Accident occupational injuries	1.30E-08	1.30E-08	1.30E-08
Truck	Suburban	Accident nonoccupational injuries	3.80E-07	3.80E-07	3.80E-07
Truck	Urban	Normal nonoccupational fatalities	1.00E-07	1.00E-07	1.00E-07
Truck	Urban	Accident occupational fatalities	2.10E-09	2.10E-09	2.10E-09
Truck	Urban	Accident nonoccupational fatalities	7.50E-09	7.50E-09	7.50E-09
Truck	Urban	Accident occupational injuries	1.30E-08	1.30E-08	1.30E-08
Truck	Urban	Accident nonoccupational injuries	3.70E-07	3.70E-07	3.70E-07
Rail	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Rural	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Rural	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Rural	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08
Rail	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Suburban	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Suburban	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Suburban	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08
Rail	Urban	Normal nonoccupational fatalities	1.30E-07	1.30E-07	1.30E-07
Rail	Urban	Accident occupational fatalities	1.81E-09	1.81E-09	1.81E-09
Rail	Urban	Accident nonoccupational fatalities	2.64E-08	2.64E-08	2.64E-08
Rail	Urban	Accident occupational injuries	2.46E-07	2.46E-07	2.46E-07
Rail	Urban	Accident nonoccupational injuries	5.12E-08	5.12E-08	5.12E-08

[a] Nonradiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609.

[b] Unit risk factors for general-commerce truck and rail transportation of spent fuel, units are per kilometer for truck, per railcar kilometer for normal rail, and per train-kilometer for rail accidents. (Note: for general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

[c] Unit risk factors for general-commerce truck and rail transportation of defense high-level waste; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: For general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

[d] Unit risk factors for general-commerce truck and rail transportation of commercial high-level waste from West Valley; units are per kilometer for truck, per railcar-kilometer for normal rail, and per train-kilometer for rail accidents. (Note: For general-commerce rail, 1 train-kilometer is equivalent to 1 railcar-kilometer.)

[e] 1.50E-08 = 1.5×10^{-8}.

Table A-11. Radiological risk factors for shipments from MRS facility[A]

			Consolidated spent fuel					
			100-ton cask			150-ton cask		
Mode	Zone	Hazard group	MRS-salt[B]	MRS-tuff[B]	MRS-basalt[B]	MRS-salt[B]	MRS-tuff[B]	MRS-basalt[B]
Rail	Rural	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Rural	Normal nonoccupational fatalities	8.32E-10[C]	8.32E-10	8.32E-10	8.32E-10	8.32E-10	8.32E-10
Rail	Rural	Accident non-occupational fatalities	6.58E-12	4.88E-12	6.56E-12	1.76E-11	1.22E-11	2.02E-11
Rail	Suburban	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Suburban	Normal nonoccupational fatalities	3.36E-08	3.36E-08	3.36E-08	3.36E-08	3.36E-08	3.36E-08
Rail	Suburban	Accident nonoccupational fatalities	1.29E-08	9.88E-09	1.29E-08	3.46E-08	2.38E-08	3.94E-08
Rail	Urban	Normal occupational fatalities	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10	6.68E-10
Rail	Urban	Normal nonoccupational fatalities	7.98E-09	7.98E-09	7.98E-09	7.98E-09	7.98E-09	7.98E-09
Rail	Urban	Accident nonoccupational fatalities	3.10E-08	2.38E-08	3.10E-08	8.30E-08	5.76E-08	9.50E-08
			Secondary wastes					
			100-ton Cask			150-ton Cask		
Mode	Zone	Hazard group	MRS-HRDWR[D]	MRS-HAW[E]	MRS-TRU[F]	MRS-HRDWR[D]	MRS-HAW[E]	MRS-TRU[F]
Rail	Rural	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Rural	Normal nonoccupational fatalities	3.34E-10	3.34E-10	2.40E-10	3.34E-10	3.34E-10	2.40E-10
Rail	Rural	Accident nonoccupational fatalities	3.46E-16	2.34E-11	3.28E-17	8.50E-16	3.98E-11	3.28E-17
Rail	Suburban	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Suburban	Normal nonoccupational fatalities	1.34E-08	1.34E-08	9.66E-09	1.34E-08	1.34E-08	9.66E-09
Rail	Suburban	Accident nonoccupational fatalities	3.58E-14	2.12E-08	2.28E-14	9.80E-14	3.62E-08	2.28E-14
Rail	Urban	Normal occupational fatalities	2.68E-10	2.68E-10	1.56E-10	2.68E-10	2.68E-10	1.56E-10
Rail	Urban	Normal nonoccupational fatalities	3.20E-09	3.20E-09	2.30E-09	3.20E-09	3.20E-09	2.30E-09
Rail	Urban	Accident nonoccupational fatalities	1.80E-13	3.86E-07	4.18E-13	2.74E-13	6.64E-07	4.18E-13

[A] To convert factors to risk per mile, multiply by 1.609. Based on 1 man-rem = 2×10^{-4} latent-cancer fatality plus first- and second-generation genetic effects.

[B] Unit risk factors for dedicated-rail transportation of consolidated spent fuel packaged for shipment to either a salt repository, a tuff repository, or a basalt repository, expressed as risk per 5 railcar-kilometers.

[C] Unit risk factors for dedicated-rail transportation of the transuranic waste (TRU) generated during spent-fuel consolidation, expressed as risk per 1 railcar-kilometer.

[D] Unit risk factors for dedicated-rail transportation of spent-fuel-assembly hardware expressed as risk per 2 railcar-kilometers; packaging is the same regardless of repository site.

[E] Unit risk factors for dedicated-rail transportation of high-activity low-level waste (HAW) generated during spent-fuel consolidation, expressed as risk per 2 railcar-kilometers; packaging is the same regardless of repository site.

Table A-12. Nonradiological risk factors for shipments from MRS facility[A]

			Consolidated spent fuel[B]	Secondary waste		
Mode	Zone	Hazard group	MRS-repository	MRS-HRDWR[C]	MRS-HAW[D]	MRS-TRU[E]
Rail	Rural	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational fatalities	1.27E-07[F]	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident occupational injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Rural	Accident non-occupational injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Normal nonoccupational fatalities	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident occupational fatalities	1.27E-07	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident Occupational Injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Suburban	Accident Non-occupational Injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Normal nonoccupational fatalities	6.50E-07	2.60E-07	2.60E-07	1.30E-07
Rail	Urban	Accident occupational fatalities	1.27E-07	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident nonoccupational fatalities	1.85E-06	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident Occupational Injuries	1.74E-05	0.00E+00	0.00E+00	0.00E+00
Rail	Urban	Accident Non-occupational Injuries	3.60E-06	0.00E+00	0.00E+00	0.00E+00

[A] Nonradiological risk factors per kilometer of travel. To convert factors to risk per mile, multiply by 1.609.

[B] Unit risk factors for dedicated-rail transportation of spent fuel in 100- and 150-ton casks to a salt repository, a tuff repository, or a basalt repository; expressed as risk per kilometer for normal transportation and as risk per train-kilometer for accidents.

[C] Unit risk factors for dedicated-rail transportation of spent-fuel-assembly hardware, expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents; packaging is not affected by repository site.

[D] Unit risk factors for dedicated-rail transportation of the high-activity low-level waste (HAW) generated during the consolidation of spent fuel; expressed as risk per railcar-kilometer for normal transportation and as risk per train-kilometer for accidents.

[E] Unit risk factors for dedicated-rail transportation of the contact-handled transuranic waste (TRU) generated during the consolidation of spent fuel; expressed as risk per railcar-kilometer or normal transportation and as risk per train-kilometer for accidents.

Table A-13. Distance per shipment from selected[a] reactors and the MRS facility

Reactor	Distance (miles)					
	Salt			Tuff	Basalt	MRS
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)	(Oak Ridge)
Maine Yankee (Maine)						
Truck	1,570	2,150	2,570	3,040	3,107	1120
Rail	1,920	2,180	2,750	3,270	3,150	1480
Crystal River (Florida)						
Truck	579	1,670	2,310	2,600	2,990	639
Rail	571	1,699	2,450	3,000	3,210	698
Quad-Cities (Illinois)						
Truck	959	1,040	1,300	1,780	1,910	714
Rail	1,080	937	1,480	2,000	1,980	861
Palo Verde (Arizona)						
Truck	1,908	789	509	606	1,550	1920
Rail	1,950	933	1,790	652	1,690	2290
Trojan (Oregon)						
Truck	2,780	1,850	1,190	1,330	302	2630
Rail	2,919	2,210	1,250	1,460	301	2B90
MRS facility						
Truck	NA[b]	NA	NA	NA	NA	NA
Rail	520	1,410	1,950	1,470	1,620	NA

[a] These reactors were chosen as representative of regions throughout the country.
[b] NA = not applicable.

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Table A-14. Distance per shipment from sources of high-level waste

Source	Distance (miles)				
	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
Hanford					
Truck	2,610	1660	1,010	1,150	NA[a]
Rail	2,670	1,730	1,070	1,288	NA
Idaho National Engineering Laboratory					
Truck	2,160	1,210	604	740	610
Rail	2,110	1,200	555	763	696
Savannah River Plant					
Truck	568	1,420	2,060	2,350	2,740
Rail	644	1,520	2,200	2,750	2,890
West Valley					
Truck	1,160	1,580	2,000	2,750	2,550
Rail	1,450	1,690	2,100	2,860	2,660

[a] NA = not applicable.
[b] Commercial high-level waste.

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Table A-15. Total cask-miles for shipments in the authorized and the improved-performance systems (one-way million miles)

Mode and waste type	Repository site				
	Salt			Tuff	Basalt
	Richton	Deaf Smith	Davis Canyon	(Yucca Mt.)	(Hanford)
AUTHORIZED SYSTEM					
100% truck					
Spent fuel	67.4	94.4	115.1	141.8	149.7
Defense high-level waste	28.0	26.0	28.0	33.0	35.0
Commercial high-level waste[a]	1.0	1.0	2.0	2.0	2.0
100% rail					
Spent fuel	11.0	15.4	18.8	23.2	24.6
Defense high-level waste	6.5	6.1	6.5	7.6	8.4
Commercial high-level waste[a]	0.2	0.2	0.2	0.3	0.3
Totals					
Truck from origin	96.4	121.4	145.1	176.8	186.7
Rail from origin	17.7	21.7	25.5	31.1	33.3
IMPROVED-PERFORMANCE SYSTEM					
1. All fuel to MRS facility					
100% truck from origin					
Spent fuel	48.8	48.8	48.8	48.8	48.8
Defense high-level waste	28.0	26.0	28.0	33.0	35.0
Commercial high-level waste[a]	1.0	1.0	2.0	2.0	2.0
100% rail from origin					
Spent fuel	8.0	8.0	8.0	8.0	8.0
Defense high-level waste	6.5	6.1	6.5	7.6	8.4
Commercial high-level waste[a]	0.2	0.2	0.2	0.3	0.3
Rail from MRS facility[b]					
100-ton casks[c]	6.3	15.3	20.6	26.3	25.0
150-ton casks[c]	2.1	5.0	6.7	11.2	8.7
Totals, 100-ton casks					
Truck from origin[d]	84.1	91.1	98.9	110.1	110.8
Rail from origin	21.0	29.6	35.3	42.2	41.7
Totals, 150-ton casks					
Truck from origin[d]	79.9	80.8	85.0	95.0	94.5
Rail from origin	16.8	19.3	21.4	27.1	25.4
2. Western-reactor spent fuel to repository					
Totals, 100-ton casks					
Truck from origin[d]	83.7	85.1	90.4	99.8	101.4
Rail from origin	20.5	27.6	32.5	38.6	38.4
Totals, 150-ton casks					
Truck from origin[d]	80.0	75.8	77.0	86.4	86.8
Rail from origin	16.7	18.3	19.0	25.1	23.8

[a] Waste from West Valley Demonstration Project.
[b] All shipments in dedicated trains.
[c] Includes casks carrying secondary wastes.
[d] Totals for the improved-performance system include both truck shipments from origin to the MRS facility and dedicated-rail shipments from the MRS facility to the repository.

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Table A-16. Fraction of travel in population zones from selected reactors and the MRS[a]

Reactor	Salt: Richton Truck	Salt: Richton Rail	Salt: Deaf Smith Truck	Salt: Deaf Smith Rail	Salt: Davis Canyon Truck	Salt: Davis Canyon Rail	Tuff (Yucca Mt.) Truck	Tuff (Yucca Mt.) Rail	Basalt (Hanford) Truck	Basalt (Hanford) Rail	MRS Facility Truck	MRS Facility Rail
Maine Yankee (Maine)												
Urban	.01	.02	.01	.03	.01	.01	.01	.01	.01	.02	.01	.03
Suburban	.43	.48	.35	.34	.28	.23	.26	.21	.26	.27	.48	.49
Rural	.57	.50	.64	.63	.71	.76	.74	.78	.73	.71	.51	.48
Crystal River (Florida)												
Urban	0	.01	.01	.02	0	.01	.01	.01	.01	.01	0	.01
Suburban	.19	.18	.23	.24	.22	.17	.17	.16	.19	.18	.32	.26
Rural	.81	.81	.77	.74	.78	.82	.82	.83	.80	.82	.68	.73
Quad-Cities (Illinois)												
Urban	0	.02	0	0	.01	.01	0	.01	0	.01	0	.04
Suburban	.19	.24	.18	.13	.11	.08	.12	.09	.10	.12	.33	.24
Rural	.81	.74	.82	.86	.88	.91	.88	.90	.90	.87	.67	.72
Palo Verde (Arizona)												
Urban	.01	.03	.02	.01	.02	.02	.02	.01	.02	.02	.01	.01
Suburban	.15	.19	.09	.10	.08	.20	.14	.09	.23	.25	.14	.15
Rural	.84	.78	.89	.90	.90	.78	.85	.90	.75	.73	.84	.84
Trojan (Oregon)												
Urban	0	.01	.01	.01	0	.01	0	.02	0	.01	0	.01
Suburban	.16	.11	.13	.09	.19	.14	.18	.10	.35	.17	.17	.11
Rural	.84	.88	.86	.90	.80	.85	.82	.89	.64	.82	.83	.88
MRS facility (Tennessee)												
Urban		.01		.02		.02		.02		.01		
Suburban	NA[b]	.30	NA	.16	NA	.12	NA	.12	NA	.11	NA	NA
Rural		.69		.82		.87		.86		.88		

[a] These reactors were chosen as representative of regions throughout the country.
[b] NA = not applicable.

Table A-17. Fraction of travel in population zones from high-level waste sources

Waste source	Salt: Richton Truck	Salt: Richton Rail	Salt: Deaf Smith Truck	Salt: Deaf Smith Rail	Salt: Davis Canyon Truck	Salt: Davis Canyon Rail	Tuff (Yucca Mt) Truck	Tuff (Yucca Mt) Rail	Basalt (Hanford) Truck	Basalt (Hanford) Rail
Hanford										
Urban	.01	0	.01	.01	0	0	0	.01	NA	NA
Suburban	.16	.11	.12	.10	.19	.15	.18	.10	NA	NA
Rural	.84	.89	.87	.89	.81	.84	.82	.89	NA	NA
Idaho National Engr Lab										
Urban	0	.01	.01	.01	.01	.01	.01	.01	0	0
Suburban	.15	.10	.10	.11	.21	.22	.19	.11	.15	.12
Rural	.85	.90	.89	.88	.78	.77	.80	.88	.85	.88
Savannah River Plant										
Urban	.01	.03	.01	.02	0	.02	.01	.02	0	.01
Suburban	.30	.26	.23	.21	.22	.19	.17	.21	.19	.17
Rural	.69	.72	.76	.78	.77	.79	.82	.78	.81	.82
West Valley										
Urban	.01	.03	0	.02	.01	.02	.01	.02	.01	.01
Suburban	.32	.33	.30	.21	.22	.18	.20	.21	.21	.17
Rural	.67	.64	.70	.78	.77	.80	.79	.78	.78	.82

The numbers of shipments from each reactor to the repository and to the MRS facility are given in Tables A-18 and A-19, respectively. The numbers are different because of the difference in the waste-acceptance schedules for the authorized system and the improved-performance system (see Tables A-6 and A-7). Table A-20 provides information on the numbers of shipments to the repository or MRS facility and the numbers of shipments from the MRS facility.

A.8.3.8 Results of population-risk analyses

The risks of radioactive-material transportation must be evaluated for both radiological and nonradiological effects. Since a package does emit small amounts of radiation, a shipment exposes the public during all phases of its journey. People are exposed at stops and along routes even when the package is moving. In addition to the radiological effects, transportation increases the levels of air pollution. Any equivalent-weight shipment of potatoes, bricks, or other nonradioactive materials would have the same effect, but that effect must be evaluated for a complete analysis. In fact, even in most transportation accidents, the traumatic injuries and deaths resulting from an impact or a fire may far outweigh any radiological consequences. Accordingly, in evaluating the potential consequences or risk of any radioactive-material shipment, the injuries and deaths from both radiological and nonradiological causes must be considered.

Tables A-21, A-22, and A-23 summarize the results of the analysis for each of the scenarios evaluated for the authorized system and the improved-performance system. Table A-21, for the authorized system, estimates the total radiological and nonradiological risks for each of the sites and for the cases where all shipments are assumed to be made by truck or by rail. Table A-22 which estimates risks for the improved performance system, shows the results for shipments from the MRS facility in 100-ton casks, which carry disposal containers ready for emplacement in the repository and 150 ton casks which carry thin-wall canisters. Table A-23 is analogous to Table A-22 except that it presents results for the scenarios in which spent fuel from Western reactors is sent directly to the repository, rather than the MRS facility. In all scenarios it was assumed that both defense and commercial high-level waste would be shipped directly to the repository.

Results for two scenarios (the authorized system and one case for the improved-performance system) are presented in more detail in Tables A-24 through A-31. Results are presented by waste type, normal or accident conditions, and population group. Similar details are available in the report by Cashwell et al. (1985) for all scenarios evaluated for this environmental assessment.

Table A-18. Number of shipments to a repository from each reactor site (authorized system)

Reactor name	100% Truck	100% Rail	Reactor name	100% Truck	100% Rail
Farley 1	120	18	Millstone 1	804	111
Farley 2	46	7	Millstone 2	805	106
Palo Verde 1	511	72	Millstone 3	36	6
Palo Verde 2	484	70	Monticello	693	96
Palo Verde 3	448	63	Prairie Island 1	650	92
Arkansas Nuclear One 1	762	108	Prairie Island 2	631	90
Arkansas Nuclear One 2	187	27	Fort Calhoun 1	534	76
Calvert Cliffs 1	893	127	Humboldt Bay	86	12
Calvert Cliffs 2	853	122	Diablo Canyon 2	236	34
Pilgrim 1	761	105	Diablo Canyon 1	279	40
Robinson 2	581	83	Susquehanna 1	652	90
Brunswick 2	799	111	Susquehanna 2	614	85
Brunswick 1	791	109	Peach Bottom 2	1126	156
Perry 1	806	110	Peach Bottom 3	1126	156
Perry 2	747	104	Limerick 1	679	95
Dresden 1	136	18	Limerick 2	421	59
Dresden 2	909	126	Trojan	330	18
Dresden 3	825	114	Fitzpatrick	614	107
Quad Cities 1	862	119	Indian Point 3	714	102
Quad Cities 2	815	113	Seabrook 1	486	69
Zion 1	858	122	Seabrook 2	320	46
Zion 2	824	117	Salem 1	791	113
LaSalle 1	572	79	Salem 2	764	109
LaSalle 2	572	79	Hope Creek 1	509	71
Byron 1	638	88	Ginna	503	71
Byron 2	631	86	Rancho Seco 1	721	103
Braidwood 1	568	83	Summer	12	2
Connecticut Yankee	702	100	San Onofre 1	203	29
Indian Point 1	80	11	San Onofre 2	306	44
Indian Point 2	762	108	San Onofre 3	347	50
Big Rock Point	104	14	South Texas Project 1	594	82
Palisades	796	113	South Texas Project 2	592	82
Midland 2	373	49	Browns Ferry 1	699	135
Midland 1	334	46	Browns Ferry 2	695	140
La Crosse	143	19	Browns Ferry 3	986	137
Fermi 2	609	85	Sequoyah 1	444	46
Oconee 1	759	108	Sequoyah 2	425	42
Oconee 2	612	87	Watts Bar 1	518	74
Oconee 3	779	111	Watts Bar 2	524	74
McGuire 1	115	17	Bellefonte 1	444	64
McGuire 2	73	11	Bellefonte 2	327	47
Beaver Valley 1	735	104	Hartsville A1	463	65
Beaver Valley 2	272	39	Hartsville A2	328	45
Crystal River 3	676	96	Yellow Creek 1	90	13
Turkey Point 3	695	99	Yellow Creek 2	50	8
Turkey Point 4	694	99	Comanche Peak 1	412	58
St. Lucie 1	894	113	Comanche Peak 2	368	53
St. Lucie 2	486	70	Davis-Besse 1	248	31
Hatch 1	312	43	Callaway 1	360	51
Hatch 2	289	40	Vermont Yankee	675	93
Vogtle 1	547	78	Surry 1	748	102
Vogtle 2	416	60	Surry 2	620	77
River Bend 1	465	65	North Anna 1	365	47
Clinton 1	528	74	North Anna 2	295	38
Cook 1	948	135	WNP 2	650	90
Cook 2	933	133	WNP 1	394	56
Duane Arnold	562	79	WNP 3	617	89
Oyster Creek	777	108	Point Beach 1	620	88
Wolf Creek	191	27	Point Beach 2	591	84
Shoreham	270	38	Kewaunee	634	90
Waterford 3	421	61	Yankee	340	48
Maine Yankee	980	140	Brunswick 2	72	10
Three Mile Island 1	723	103	Brunswick 1	80	11
Grand Gulf 1	247	35	Morris BWR pool	150	20
Grand Gulf 2	340	48	Morris PWR pool	175	25
Cooper	771	107	West Valley BWR pool	17	2
Nine Mile Point 1	700	97	West Valley PWR pool	60	8
Nine Mile Point 2	243	33			
				70,553	9,927

Table A-19. Number of shipments to an MRS facility from eastern and western reactors

Reactor name	100% by Truck	100% by Rail	Reactor name	100% by Truck	100% by Rail
Farley 1	387	56	Humboldt Bay[a]	86	12
Farley 2	513	45	Diablo Canyon 2[a]	209	30
Palo Verde 1[a]	366	52	Diablo Canyon 1[a]	252	36
Palo Verde 2[a]	339	49	Susquehanna 1	516	71
Palo Verde 3[a]	332	47	Susquehanna 2	483	67
Arkansas Nuclear One 1	762	108	Peach Bottom 2	1,126	156
Arkansas Nuclear One 2	495	43	Peach Bottom 3	1,126	156
Calvert Cliffs 1	893	127	Limerick 1	500	70
Calvert Cliffs 2	853	121	Limerick 2	287	40
Pilgrim 1	761	105	Trojan[a]	805	117
Robinson 2	581	83	Fitzpatrick	864	127
Brunswick 2	799	111	Indian Point 3	714	102
Brunswick 1	791	109	Seabrook 1	343	49
Harris 1	160	23	Seabrook 2	177	26
Perry 1	722	100	Salem 1	791	113
Perry 2	579	80	Salem 2	764	109
Dresden 1	136	18	Hope Creek 1	365	51
Dresden 2	909	126	Ginna	503	71
Dresden 3	825	114	Rancho Seco 1[a]	721	103
Quad-Cities 1	862	119	Summer	215	31
Quad-Cities 2	815	113	San Onofre 1[a]	203	29
Zion 1	858	122	San Onofre 2[a]	306	44
Zion 2	824	117	San Onofre 3[a]	348	49
LaSalle 1	669	93	South Texas Project 1	539	77
LaSalle 2	632	87	South Texas Project 2	453	64
Byron 1	593	85	Browns Ferry 1	944	135
Byron 2	552	78	Browns Ferry 2	821	140
Braidwood 1	570	81	Browns Ferry 3	986	137
Braidwood 2	484	69	Sequoyah 1	588	113
Connecticut Yankee	702	100	Sequoyah 2	571	108
Indian Point 1	80	11	Watts Bar 1	465	66
Indian Point 2	762	108	Watts Bar 2	424	61
Big Rock Point	104	14	Bellefonte 1	315	45
Palisades	796	113	Bellefonte 2	199	29
Midland 2	304	43	Hartsville A1	284	40
Midland 1	261	37	Hartsville A2	194	26
La Crosse	143	19	Comanche Peak 1	294	42
Fermi 2	609	85	Comanche Peak 2	257	33
Oconee 1	759	108	Davis Besse 1	321	43
Oconee 2	612	87	Callaway 1	260	38
Oconee 3	779	111	Vermont Yankee	675	93
McGuire 1	334	44	Surry 1	748	106
McGuire 2	268	39	Surry 2	620	88
Catawba 1	241	31	North Anna 1	469	58
Catawba 2	198	25	North Anna 2	420	50
Beaver Valley 1	735	105	WNP 2[a]	605	84
Beaver Valley 2	154	22	WNP 1[a]	251	36
Crystal River 3	676	96	WNP 3[a]	448	63
Turkey Point 3	695	99	Point Beach 1	620	88
Turkey Point 4	694	99	Point Beach 2	591	84
St. Lucie 1	914	130	Kewaunee	634	90
St. Lucie 2	375	54	Yankee	340	48
Hatch 1	512	61	Brunswick 2	72	10
Hatch 2	482	57	Brunswick 1	80	11
Vogtle 1	415	59	Shoreham	201	28
Vogtle 2	290	41	Waterford 3	291	42
River Bend 1	329	45	Maine Yankee	980	140
Clinton 1	407	57	Three Mile Island	723	103
Cook 1	948	135	Grand Gulf 1	318	45
Cook 2	933	133	Grand Gulf 2	210	30
Arnold	572	79	Cooper	771	107
Oyster Creek	777	108	Nine Mile Point 1	700	97
Wood Creek	184	27	Nine Mile Point 2	185	26

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Table A-19. Number of shipments to an MRS facility from eastern and western reactors

Reactor name	100% by Truck	100% by Rail	Reactor name	100% by Truck	100% by Rail
Millstone 1	804	111	Fort Calhoun 1	534	76
Millstone 2	949	135	Morris BWR pool	150	20
Millstone 3	227	33	Morris PWR pool	175	25
Monticello	693	96	West Valley BWR pool	17	2
Prairie Island 1	650	92	West Valley PWR pool	60	8
Prairie Island 2	631	90			
			Total	70,568	9,934

[a] Considered a western reactor for this analysis.

Table A-20a. Number of cask shipments: total cask-shipments from reactors

Destination	Mode	Number of cask shipments PWR	BWR	Total
Repository	100 % truck	43,611	26,942	70,553
	100 % rail	6,190	3,737	9,927
MRS facility, all spent fuel	100 % Truck	44,222	26,346	70,568
	100 % Rail	6,267	3,667	9,934
MRS facility, eastern spent fuel only	100 % Truck	40,915	24,382	65,297
	100 % Rail	5,793	3,390	9,183

Table A-20b. Number of cask-shipments: total cask shipments of consolidated spent fuel from MRS facility[a]

Destination (repository site)	Cask size (tons)	All spent fuel	Eastern fuel only
Salt sites[b]	100	8,074	7,500
	150	2,103	1,900
Tuff	100	8,050	7,500
	150	3,186	3,000
Basalt	100	6,610	6,100
	150	1,823	1,700

[a] Estimates of shipment numbers.
[b] Richton, Deaf Smith, or Davis Canyon.

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Table A-21. Summary of the risks of transporting spent fuel and high-level wastes for disposal in the authorized system[a]

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt)	Basalt (Hanford)
100% truck					
Radiological	6.3	7.9	9.5	11	12
Nonradiological	19	24	30	36	39
100% rail					
Radiological	0.2	0.2	0.3	0.3	0.3
Nonradiological	1.8	2.1	2.6	3.0	3.2

[a] Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of fatalities from radiological causes include first- and second-generation genetic effects.

Table A-22. Summary of the risks of transportation for the improved-performance system[a,b]

Mode and risk type	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
100% Truck, 100-ton cask[c,d]					
Radiological	5.3	5.4	5.4	5.7	5.7
Nonradiological	21	30	35	42	39
100% rail, 100-ton cask[d,e]					
Radiological	0.2	0.3	0.3	0.3	0.3
Nonradiological	6.9	16	22	27	24
100% truck, 150-ton cask[c,f]					
Radiological	5.3	5.3	5.4	5.7	5.7
Nonradiological	17	19	21	27	23
100% rail, 150-ton cask[e,f]					
Radiological	0.2	0.2	0.2	0.3	0.2
Nonradiological	3.0	5.4	6.9	12	7.8

[a] All spent fuel assumed to be sent first to the MRS facility and from there to the repository; all high-level waste assumed to be sent directly to the repository.

[b] Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of radiological fatalities include first- and second-generation genetic effects.

[c] Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

[d] Shipment in general-commerce trains from reactors and HLW processing plants; shipment in dedicated trains from MRS facility.

[e] The 100-ton cask carries ready-to-emplace disposal containers.

[f] The 150-ton cask carries thin-walled canisters to be encapsulated in disposal containers at the repository.

Table A-23. Summary of the risks of transporting for disposal in the improved-performance system[a,b]

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
100% truck, 100-ton cask[c,d]					
Radiological	5.4	5.0	5.0	5.3	5.3
Nonradiological	20	28	32	39	35
100% rail, 100-ton cask[d,e]					
Radiological	0.2	0.2	0.3	0.3	0.3
Nonradiological	6.5	15	20	25	22
100% truck, 150-ton cask[c,f]					
Radiological	5.3	5.0	5.0	5.2	5.2
Nonradiological	17	18	19	24	21
100% rail, 150-ton cask[d,f]					
Radiological	0.2	0.2	0.2	0.3	0.2
Nonradiological	2.8	5.0	6.4	11	7.3

[a] Spent fuel from eastern reactors assumed to be sent first to the MRS facility and from there to the repository; spent fuel from western reactors assumed to be sent directly to the repository. All high-level waste assumed to be sent directly to the repository.

[b] Risks expressed in numbers of fatalities from radiological and nonradiological causes. The numbers of radiological fatalities include first- and second-generation genetic effects.

[c] Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

[d] Shipment in general-commerce trains from reactors and HLW processing plants, shipment in dedicated trains from MRS facility.

[e] The 100-ton cask carries ready-to-emplace disposal containers.

[f] The 150-ton cask carries thin-walled canisters to be encapsulated in disposal containers at the repository.

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Table A-24. Transportation risks for authorized system from spent fuel only

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[a]					
Truck transportation					
Normal occupational fatalities	0.7	1.0	1.2	1.4	1.6
Normal nonoccupational fatalities	3.8	5.2	6.5	7.7	8.4
Accident nonoccupational fatalities	0.02	0.03	0.03	0.04	0.04
Total fatalities	4.6	6.2	7.7	9.2	10
Rail transportation					
Normal occupational fatalities	0.06	0.07	0.09	0.1	0.1
Normal nonoccupational fatalities	0.08	0.08	0.1	0.1	0.1
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.2	0.2	0.2	0.2	0.2
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.2	0.4	0.4	0.4
Accident occupational fatalities	2.7	3.9	5.2	6.4	6.8
Accident nonoccupational fatalities	9.6	14	18	23	24
Accident occupational injuries	5.5	7.7	10	12	13
Accident nonoccupational injuries	160	220	290	370	380
Total fatalities	13	18	24	29	31
Rail transportation					
Normal nonoccupational fatalities	0.1	0.1	0.1	0.2	0.2
Accident occupational fatalities	0.07	0.09	0.1	0.1	0.1
Accident nonoccupational fatalities	1	1.3	1.7	2.1	2.1
Accident occupational injuries	9.2	12	15	19	19
Accident nonoccupational injuries	1.9	2.4	3.2	4.0	4.0
Total fatalities	1.2	1.5	1.9	2.4	2.4

[a] Radiological fatalities include first- and second-generation genetic effects.

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Table A-25. Transportation risks for the authorized system from high-level waste only

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[a]					
Truck transportation					
Normal occupational fatalities	0.3	0.3	0.3	0.3	0.3
Normal nonoccupational fatalities	1.5	1.5	1.5	1.8	1.8
Accident nonoccupational fatalities	0.001	0.001	0.001	0.001	0.001
Total fatalities	1.8	1.8	1.8	2.1	2.1
Rail transportation					
Normal occupational fatalities	0.03	0.03	0.03	0.04	0.04
Normal nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Accident nonoccupational fatalities	0.0011	0.001	0.001	0.002	0.001
Total fatalities	0.6	0.06	0.07	0.08	0.08
NONRADIOLOGICAL RISK					
Truck transportation					
Normal occupational fatalities	0.02	0.1	0.05	0.1	0.02
Accident occupational fatalities	1.4	1.3	1.3	1.6	1.6
Accident nonoccupational fatalities	4.8	4.7	4.7	5.7	5.8
Accident occupational injuries	2.7	2.6	2.6	3.1	3.2
Accident nonoccupational injuries	76	75	75	90	91
Total fatalities	6.2	6.2	6.1	7.4	7.4
Rail transportation					
Normal occupational fatalities	0.03	0.04	0.04	0.04	0.04
Accident occupational fatalities	0.04	0.04	0.04	0.04	0.05
Accident nonoccupational fatalities	0.6	0.6	0.6	0.6	0.7
Accident occupational injuries	5.3	5.3	5.4	5.3	6.6
Accident nonoccupational injuries	1.1	1.1	1.1	1.1	1.4
Total fatalities	0.6	0.6	0.7	0.6	0.8

[a] Radiological fatalities include first- and second-generation genetic effects.

Table A-26. Total transportation risks for the authorized system

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[a]					
Truck transportation					
Normal occupational fatalities	1	1.3	1.5	1.7	1.9
Normal nonoccupational fatalities	5.3	6.6	8.0	9.5	10
Accident nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Total fatalities	6.3	7.9	9.5	11	12
Rail transportation					
Normal occupational fatalities	0.1	0.1	0.1	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.2
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.2	0.2	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.3	0.4	0.6	0.4
Accident occupational fatalities	4.1	5.2	6.5	8	8.4
Accident nonoccupational fatalities	14	18	23	28	30
Accident occupational injuries	8.1	10	13	16	17
Accident nonoccupational injuries	230	300	370	450	470
Total fatalities	19	24	30	37	39
Rail transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	0.1	0.1	0.2	0.2	0.2
Accident nonoccupational fatalities	1.5	1.8	2.2	2.6	2.8
Accident occupational injuries	14	17	21	25	26
Accident nonoccupational injuries	3	3.5	4.3	5.1	5.4
Total fatalities	1.8	2.1	2.6	3.0	3.2

[a] Radiological fatalities include first- and second-generation genetic effects.

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Table A-27. Transportation risks for the improved-performance system from shipping spent fuel from reactors to the MRS facility[a]

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[b]					
Truck transportation					
Normal occupational fatalities	0.6	0.6	0.6	0.6	0.6
Normal nonoccupational fatalities	3	3	3	3	3
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	3.6	3.6	3.6	3.6	3.6
Rail transportation					
Normal occupational fatalities	0.05	0.05	0.05	0.05	0.05
Normal nonoccupational fatalities	0.07	0.07	0.07	0.07	0.07
Accident nonoccupational fatalities	0.02	0.02	0.02	0.02	0.02
Total fatalities	0.1	0.1	0.1	0.1	0.1
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.2	0.2	0.2	0.2	0.2
Accident occupational fatalities	2	2	2	2	2
Accident nonoccupational fatalities	7	7	7	7	7
Accident occupational injuries	4.1	4.1	4.1	4.1	4.1
Accident nonoccupational injuries	120	120	120	120	120
Total fatalities	9.1	9.1	9.1	9.1	9.1
Rail transportation					
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.1
Accident occupational fatalities	0.05	0.05	0.05	0.05	0.05
Accident nonoccupational fatalities	0.8	0.8	0.8	0.8	0.8
Accident occupational injuries	7	7	7	7	7
Accident nonoccupational injuries	1.4	1.4	1.4	1.4	1.4
Total fatalities	0.9	0.9	0.9	0.9	0.9

[a] Estimated risks of shipping all spent fuel from reactors to the MRS facility. The risks are the same for all four of the scenarios discussed in the text.

[b] Radiological fatalities include first- and second-generation genetic effects.

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Table A-28. Transportation risks for the improved-performance system from shipping consolidated spent fuel from the MRS facility to the repository[a]

Risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[b]					
Normal occupational fatalities	0.002	0.004	0.005	0.006	0.005
Normal nonoccupational fatalities	0.02	0.02	0.02	0.03	0.03
Accident nonoccupational fatalities	0.006	0.01	0.01	0.01	0.01
Total fatalities	0.02	0.04	0.04	0.05	0.04
NONRADIOLOGICAL RISK					
Normal nonoccupational fatalities	0.01	0.09	0.1	0.1	0.07
Accident occupational fatalities	0.3	0.9	1.3	1.6	1.4
Accident nonoccupational fatalities	5	14	19	24	21
Accident occupational injuries	47	130	180	220	190
Accident nonoccupational injuries	9.7	26	36	46	40
Total fatalities	5.4	15	20	25	22

[a] Estimated risks from shipping consolidated spent fuel from the MRS facility to the repository. All shipments assumed to be by dedicated train in 100-ton casks carrying ready-to-emplace disposal containers.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-29. Transportation risks for the improved-performance system from shipping secondary waste from the MRS facility to the repository[a]

Type of risk	Salt Richton	Salt Deaf Smith	Salt Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
	RADIOLOGICAL RISK[b]				
Normal occupational fatalities	0.0008	0.001	0.002	0.002	0.002
Normal nonoccupational fatalities	0.005	0.008	0.009	0.01	0.014
Accident nonoccupational fatalities	0.006	0.01	0.01	0.02	0.02
Total fatalities	0.008	0.02	0.02	0.03	0.02
	NONRADIOLOGICAL RISK				
Normal nonoccupational fatalities	0.008	0.02	0.03	0.04	0.03
Accident occupational fatalities					
Accident nonoccupational fatalities					
Accident occupational injuries					
Accident nonoccupational injuries					
Total fatalities	0.008	0.02	0.03	0.04	0.03

[a] Estimated risks of shipping secondary waste (spent-fuel-assembly hardware, high-activity low-level waste, and contact-handled transuranic waste) from the MRS facility to the repository. All secondary-waste shipments assumed to be by dedicated train in 100-ton casks.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-30. Transportation risks for the improved-performance system from shipping high-level waste to the repository[a]

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[b]					
Truck transportation					
Normal occupational fatalities	0.3	0.3	0.3	0.3	0.3
Normal nonoccupational fatalities	1.5	1.5	1.5	1.8	1.8
Accident nonoccupational fatalities	0.001	0.001	0.001	0.001	0.001
Total fatalities	1.8	1.8	1.8	2.1	2.1
Rail transportation					
Normal occupational fatalities	0.03	0.03	0.03	0.04	0.04
Normal nonoccupational fatalities	0.03	0.03	0.03	0.04	0.04
Accident nonoccupational fatalities	0.001	0.001	0.001	0.002	0.001
Total fatalities	0.06	0.06	0.07	0.08	0.07
NONRADIOLOGICAL RISK					
Truck transportation					
Normal nonoccupational fatalities	0.02	0.1	0.05	0.1	0.02
Accident occupational fatalities	1.4	1.3	1.3	1.6	1.6
Accident nonoccupational fatalities	4.8	4.7	4.7	5.7	5.8
Accident occupational injuries	2.7	2.6	2.6	3.1	3.2
Accident nonoccupational injuries	76	75	75	90	91
Total fatalities	6.2	6.2	6.2	7.4	7.4
Rail transportation					
Normal nonoccupational fatalities	0.03	0.04	0.04	0.06	0.04
Accident occupational fatalities	0.04	0.04	0.04	0.05	0.05
Accident nonoccupational fatalities	0.6	0.6	0.6	0.7	0.7
Accident occupational injuries	5.3	5.3	5.4	6.9	6.6
Accident nonoccupational injuries	1.4	1.1	1.1	1.4	1.4
Total fatalities	0.63	0.64	0.66	0.84	0.79

[a] Estimated risk of shipping high-level waste directly to the repository. All shipments assumed to be in 100-ton casks.

[b] Radiological fatalities include first- and second-generation genetic effects.

Table A-31. Total transportation risks for the improved-performance system[a]

Mode and risk type	Salt: Richton	Salt: Deaf Smith	Salt: Davis Canyon	Tuff (Yucca Mt.)	Basalt (Hanford)
RADIOLOGICAL RISK[b]					
Truck transportation[c]					
Normal occupational fatalities	0.9	0.8	0.9	0.9	0.9
Normal nonoccupational fatalities	4.5	4.4	4.5	4.7	4.8
Accident nonoccupational fatalities	0.03	0.05	0.05	0.06	0.05
Total fatalities	5.3	5.4	5.4	5.7	5.7
Rail transportation[d]					
Normal occupational fatalities	0.09	0.09	0.09	0.1	0.1
Normal nonoccupational fatalities	0.1	0.1	0.1	0.1	0.1
Accident nonoccupational fatalities	0.03	0.04	0.04	0.05	0.04
Total fatalities	0.2	0.3	0.3	0.3	0.3
NONRADIOLOGICAL RISK					
Truck transportation[c]					
Normal nonoccupational fatalities	0.2	0.4	0.4	0.5	0.3
Accident occupational fatalities	3.7	4.3	4.6	5.2	5.0
Accident nonoccupational fatalities	17	25	30	36	33
Accident occupational injuries	54	130	180	230	200
Accident nonoccupational injuries	200	220	230	250	250
Total fatalities	21	30	35	42	39
Rail transportation[d]					
Normal nonoccupational fatalities	0.2	0.3	0.3	0.4	0.3
Accident occupational fatalities	0.4	1.0	1.4	1.7	1.5
Accident nonoccupational fatalities	6.3	15	20	25	22
Accident occupational injuries	59	140	190	240	210
Accident nonoccupational injuries	12	25	39	49	43
Total fatalities	6.9	16	22	27	24

[a] Estimated risks of shipping (1) all spent fuel from reactors to the MRS facility, (2) consolidated spent fuel from the MRS facility to the repository, (3) secondary waste from the MRS facility to the repository, and (4) high-level waste directly to the repository. All shipments from the MRS facility assumed to be in 100-ton casks.

[b] Radiological fatalities include first- and second-generation genetic effects.

[c] Shipment by truck from reactors and HLW processing plants; shipment in dedicated trains from MRS facility to repository.

[d] The 100-ton cask carries ready-to-emplace disposal containers.

A.8.3.9 Uncertainties

The results presented here are to be used only in comparing potential repository sites, because their absolute values, though considered to be representative, have acknowledged uncertainties associated with them. Important ones include the following:

1. The risk analysis (Section A.8.2.8) was performed on a national scale, using aggregate input from large regions. As a result, these inputs are averaged and may not accurately reflect information for a specific route.

2. The packaging capacities are not known at this time nor are actual exposure rates for new casks.

3. Some inputs will be refined during the studies conducted concurrently with site characterization and during the preparation of the environmental impact statement.

A.9 COST ANALYSIS

Early efforts at defining the transportation-system equipment and operating requirements for the repository were initiated in the late 1970s, when it was recognized that transportation is an important factor in repository siting. This section summarizes the method, assumptions, and models used in analyzing the costs of waste transportation.

A.9.1 OUTLINE OF METHOD

The analysis in this environmental assessment makes use of the models developed to evaluate the costs of transporting waste to a repository. The analysis is dependent on a logistics code, WASTES, which analyzes the cost of transport and hardware requirements (Shay et al., 1985). The hardware costs, both maintenance and capital, are evaluated by using the output from WASTES. The total costs can therefore be thought of as the composite value of shipping costs, hardware capital expenditures, and maintenance allowances. All three factors are highly dependent on the assumptions underlying the analysis.

A.9.2 ASSUMPTIONS

In calculating costs, the spent-fuel discharge data published in a recent DOE report (Heeb et al., 1985) were used. In all scenarios a total of 62,000 MTU of spent fuel is shipped from individual reactor sites. The specific amounts of spent fuel to be shipped from each reactor site were selected on a yearly basis by applying the following criteria:

1. Reactors experiencing a loss of full-core-reserve (FCR) capacity within a given year were given the highest priority.

2. Reactors undergoing decommissioning were given the next highest priority 2 years after their last year of operation.

3. The oldest fuel remaining at reactors was given final priority.

The other major assumptions used in this analysis are described below (see Cashwell et al., 1985, for details).

A.9.3 MODELS

The WASTES model was used to calculate shipping costs and the size of the cask fleet. This model has been benchmarked against past analyses. A good discussion of the capabilities of WASTES is presented by Shay et al. (1985).

A.9.4 COST ESTIMATES

The costs of transporting waste in the various scenarios are shown in Table A-32. Estimates for the authorized system and two scenarios for the improved-performance system are presented in sufficient detail to show the costs of shipping the various types of waste. Only summary results are presented for the other scenarios, but details are available in the report by Cashwell et al. (1985). The results for the same two scenarios are provided in Tables A-33 and A-34 except that different detail is highlighted. In these tables, the three major cost components are shown for spent-fuel shipments only. The basis for the capital and maintenance costs is given in Tables A-35 and A-36. It should be noted in Table A-35 that the cask-maintenance costs are for 15 years--the assumed life of a cask. Table A-36 estimates the numbers of casks needed over the lifetime of the repository for each of the various scenarios.

The costs of transporting high-level waste are given in Tables A-37 and A-38 for each of the repository sites and for each mode considered.

A.9.5 LIMITATIONS OF RESULTS

The results presented should be used only to compare the potentially acceptable sites. As absolute values, they are limited for several reasons:

1. No attempt was made to escalate costs for inflation. All costs are in constant 1985 dollars.

2. The transportation-distance estimates will be affected by the selected routes.

Table A-32. Total transportation cost
(millions of dollars)

Mode and waste type	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
	Repository Site				
AUTHORIZED SYSTEM					
100% Truck					
Spent fuel	722	922	1,080	1,286	1,345
Defense high-level waste	207	195	214	237	254
Commercial high-level waste[a]	7	8	10	15	15
100% Rail					
Spent fuel	699	832	917	1,024	1,055
Defense high-level waste	272	279	278	308	308
Commercial high-level waste[a]	10	10	11	12	12
Totals					
Truck from origin	936	1,127	1,305	1,538	1,615
Rail from origin	982	1,122	1,207	1,345	1,376
IMPROVED-PERFORMANCE SYSTEM					
1. All fuel to the MRS facility					
100% truck from origin					
Spent fuel	600	600	600	600	600
Defense high-level waste	207	195	214	237	254
Commercial high-level waste[a]	7	8	10	15	15
100% rail from origin					
Spent fuel	594	593	593	593	593
Defense high-level waste	272	279	278	308	308
Commercial high-level waste[a]	10	10	11	12	12
Rail from MRS, 100-ton casks					
Spent fuel in disposal containers	421	638	728	800	693
Assembly hardware and high-activity waste	80	124	144	164	173
Contact-handled transuranic waste	8	9	9	10	10
Rail from MRS, 150-ton casks					
Spent fuel in disposal containers	157	212	236	412	248
Assembly hardware and high-activity waste	87	123	140	147	172
Contact-handled transuranic waste	8	9	10	10	11

Table A-32. Total transportation cost (Continued)
(millions of dollars)

	Repository Location				
Mode and waste type	Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
IMPROVED-PERFORMANCE SYSTEM (Continued)					
1. All fuel to the MRS facility (Continued)					
Total cost, 100-ton casks					
Truck from origin	1,323	1,576	1,709	1,828	1,748
Rail from origin	1,384	1,654	1,767	1,889	1,792
Total cost, 150-ton casks					
Truck from origin	1,065	1,149	1,210	1,422	1,301
Rail from origin	1,127	1,227	1,268	1,483	1,345
2. Western-reactor spent fuel directly to the repository					
Total cost, 100-ton casks					
Truck from origin	1,265	1,439	1,560	1,674	1,562
Rail from origin	1,328	1,537	1,640	1,760	1,628
Total cost, 150-ton casks					
Truck from origin	1,046	1,084	1,126	1,308	1,205
Rail from origin	1,109	1,182	1,206	1,394	1,271

[a] High-level waste from the West Valley Demonstration Project.

Table A-33. Costs of transportation from reactors to repository in the authorized system[a,b] (millions of dollars)

Repository site	Shipping	Capital	Maintenance	Total
ALL SHIPMENTS BY RAIL				
Richton	390	202	108	699
Deaf Smith	477	232	123	832
Davis Canyon	534	250	134	917
Yucca Mountain	604	275	146	1,024
Hanford	626	280	150	1,055
ALL SHIPMENTS BY TRUCK				
Richton	442	181	99	722
Deaf Smith	595	212	116	922
Davis Canyon	717	235	128	1,080
Yucca Mountain	876	266	145	1,286
Hanford	922	274	149	1,345

[a] Spent fuel only.
[b] Values have been rounded.

Table A-34. Costs of transportation in the improved-performance system[a,b] (millions of dollars)

Repository site	Shipping	Capital	Maintenance	Total
RAIL SHIPMENTS TO AND FROM THE MRS FACILITY				
Richton	598	248	256	1,102
Deaf Smith	799	354	212	1,365
Davis Canyon	895	277	306	1,477
Yucca Mountain	963	379	227	1,569
Hanford	906	354	211	1,471
TRUCK SHIPMENTS TO, AND RAIL SHIPMENTS FROM, THE MRS FACILITY				
Richton	623	236	250	1,108
Deaf Smith	824	342	207	1,372
Davis Canyon	919	265	300	1,485
Yucca Mountain	988	367	222	1,576
Hanford	931	342	206	1,479

[a] All spent fuel sent first to the MRS facility and from there to the repository, after consolidation. All shipments in 100-ton casks.

[b] Cost estimates do not include high-level waste, and values have been rounded.

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Table A-35. Capital and maintenance costs (millions of 1985 dollars)

Transportation mode	Capital[a]	Maintenance[b]
Reactor to MRS facility		
Truck cask	1.5	0.075
Rail cask	2.5	0.125
MRS facility to repository		
100-ton rail cask	2.5	0.125
150-ton rail cask	2.75	0.125
Rail package for transuranic waste[c]	1.6	0.075
Defense high-level waste[d]		
Truck cask	1.1	0.06
Rail cask	1.8	0.09

[a] Capital costs are for each cask and include the cost of trailer or railcar.

[b] Maintenance costs are per package-year for the assumed 15-year cask life.

[c] Based on two packages per railcar.

[d] Includes commercial high-level waste from the West Valley Demonstration Project.

Table A-36. Total requirements for transportation packaging
(Number of casks)

Mode and waste type	Repository site: Richton	Deaf Smith	Davis Canyon	Yucca Mt.	Hanford
AUTHORIZED SYSTEM					
100% truck					
Spent fuel	124	145	161	182	188
Defense high-level waste	40	43	48	50	53
Commercial high-level waste	2	2	2	4	4
100% rail					
Spent fuel	81	93	100	110	112
Defense high-level waste	34	36	38	42	44
Commercial high-level waste	2	2	2	2	2
IMPROVED-PERFORMANCE SYSTEM					
1. All spent fuel to the MRS facility					
100% truck from origin					
Spent fuel	106	106	106	106	106
Defense high-level waste	40	44	48	51	56
Commercial high-level waste	2	2	2	4	4
100% rail from origin					
Spent fuel	67	67	67	67	67
Defense high-level waste	34	37	38	42	47
Commercial high-level waste	2	2	2	2	2
Rail from MRS, 100-ton casks					
Spent fuel in disposal containers	55	70	75	80	70
High-activity waste	4	4	4	4	4
Contact-handled TRU waste	2	2	2	2	2
Rail from MRS, 150-ton casks					
Spent fuel in canisters	20	20	20	30	20
High-activity waste	8	8	8	6	10
Contact-handled TRU waste	2	2	2	2	2
2. Western-reactor spent fuel to the repository					
100% Truck from origin					
Spent fuel	111	108	106	105	106
Defense high-level waste	40	44	48	51	56
Commercial high-level waste	2	2	2	4	4
100% rail from origin					
Spent fuel	70	69	67	67	67
Defense high-level waste	34	37	38	42	47
Commercial high-level waste	2	2	2	2	2
Rail from MRS, 100-ton casks					
Spent fuel in disposal canisters	50	60	70	70	60
High-activity waste	4	4	4	4	4
Contact-handled TRU work	2	2	2	2	2
Rail from MRS, 150-ton casks					
Spent fuel in canisters	20	20	20	30	20
High-activity waste	8	8	8	6	8
Contact-handled TRU waste	2	2	2	2	2

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Table A-37. Costs of transporting high-level waste by truck[a] (millions of 1985 dollars)

Source and destination	Shipping	Capital	Maintenance	Total
Savannah River Plant				
Hanford	135	48	26	210
Yucca Mountain	110	42	23	175
Deaf Smith	63	31	17	111
Richton	34	22	12	68
Davis Canyon	97	40	22	158
Hanford				
Hanford	NA	NA	NA	NA
Yucca Mountain	10	3	3	16
Deaf Smith	15	4	4	23
Richton	24	6	4	34
Davis Canyon	9	3	3	15
Idaho National Engineering Laboratory				
Hanford	26	10	8	44
Yucca Mountain	29	10	8	47
Deaf Smith	40	12	10	62
Richton	74	16	14	105
Davis Canyon	23	10	8	41
West Valley Demonstration Plant[b]				
Hanford	9	4	2	15
Yucca Mountain	8	4	2	15
Deaf Smith	5	2	1	9
Richton	4	2	1	7
Davis Canyon	7	2	1	10

[a] Values have been rounded.

[b] Commercial high-level waste.

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Table A-38. Costs of transporting high-level waste by rail[a]
(Millions of 1985 dollars)

Source and destination	Shipping	Capital	Maintenance	Total
SRP to				
Hanford	142	65	32	240
Yucca Mountain	126	54	27	208
Deaf Smith	92	43	22	157
Richton	56	32	16	105
Davis	118	50	25	193
Hanford to				
Hanford	NA	NA	NA	NA
Yucca Mountain	15	5	4	25
Deaf Smith	20	5	4	30
Richton	26	7	5	39
Davis	14	5	4	24
INEL to				
Hanford	44	14	11	69
Yucca Mountain	48	16	12	77
Deaf Smith	64	16	12	92
Richton	91	22	16	129
Davis	39	13	10	61
West Valley to				
Hanford	7	4	2	12
Yucca Mountain	7	4	2	12
Deaf Smith	5	3.6	2	10
Richton	4	4	2	10
Davis	6	4	2	11

[a] Values have been rounded.

3. Published tariffs were used in this analysis where available; however, under the deregulation that has recently occurred, the DOE will be able to negotiate with carriers for rates and services, and shipping costs may change.

A.10 BARGE TRANSPORTATION TO REPOSITORIES

The most likely way in which barge transportation would be used to make shipments to a repository would be to complete a partial leg of the journey. In all cases, barges cannot be loaded directly from the reactor-pool loading area without the use of heavy-haul truck equipment or a railcar. In the barge scenario for eastern reactors evaluated by Tobin and Meshkov (1985), it was considered likely that a reactor within 483 kilometers (300 miles) of a large port capable of handling large railcasks and served by a railroad would ship by rail and then use a barge through an intermodal transfer. The eastern reactors for which barge transport was considered to be a feasible option are listed in Table A-39. The shipment from the reactor would then proceed as far as possible by barge, and then another intermodal transfer would occur back to a railroad. This transfer point was assumed to be either in the Gulf of Mexico or on the Mississippi River. Therefore, the shipment would arrive at the repository by railcar. The possible exception where barge loadings and unloadings could be made directly would be a specially designed cask-handling facility at the MRS facility. Because a barge has tremendous capacity (equivalent to at least four rail casks), it is highly inefficient to use small truck casks.

The results given in Table A-40 for the risk from barge transportation generally show that barge transportation increases occupational exposure for normal operations during the shipment of spent fuel. Because barge shipments require intermodal transfer at both ends of the journey, the workers involved in this activity receive relatively high radiation doses and account for the large increase in occupational exposure over the rail mode. The exposure of the public is also increased by the intermodal transfers.

The results presented in Table A-40 are a first attempt at characterizing barge transportation. The numbers are expected to be refined as further studies are conducted to provide models of similar detail as those available for the truck and rail modes. As in previous studies for truck and rail modes, when data are not well characterized, assumptions are made that tend to overpredict the actual values. However, reactor-specific results presented by Tobin and Meshkov (1985) suggest that under several circumstances the barge mode may reduce risk.

Tobin and Meshkov did not investigate the consequences of barge accidents because a previous study (Unione et al., 1978) was found to contain analyses for barge accidents that were similar to those used by Sandquist et al. (1985) for truck and rail accidents. The results of that study are shown in Tables A-41 and A-42. These results can be compared with the equivalent categories in Table A-5. Table A-42 is comparable to results for water release. The results show accidents from barges to be of the same order as for other modes.

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Table A-39. Reactor sites included in barge study

Direct to water[a]				Rail to water[b]	
Transfer at Houston[c]		Transfer at Memphis[d]		Transfer at Houston	
Plant	State	Plant	State	Plant	State
Brunswick	North Carolina	Big Rock Point	Michigan	Hatch	Georgia
Calvert Cliffs	Maryland	Browns Ferry	Alabama	McGuire	North Carolina
Crystal River	Florida	Cook	Michigan	North Anna	Virginia
Farley	Alabama	Davis-Besse	Ohio	Peach Bottom	Pennsylvania
Indian Point	New York	Dresden	Illinois	Robinson	South Carolina
Maine Yankee	Maine	Fitzpatrick	New York	Summer	South Carolina
Millstone	Connecticut	Ginna	New York	Susquehanna	Pennsylvania
Oyster Creek	New Jersey	Kewaunee	Wisconsin	Three Mile Island	Pennsylvania
Pilgrim	Massachusetts	Nine Mile Point	New York	Vermont Yankee	Vermont
Salem	New Jersey	Palisades	Michigan		
St. Lucie	Florida	Point Beach	Wisconsin		
Surry	Virginia	Sequoyah	Tennessee		
Turkey Point	Florida	Zion	Illinois		

[a] Plants located on a waterway.
[b] Plants located within 300 miles of port.
[c] Shipments to Houston are by ocean.
[d] Shipments to Memphis are by inland waterway.

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Table A-40. Projected latent cancers for shipments to repositories from reactors with barge access[a,b]

Type of transfer	Deaf Smith		Yucca Mountain		Hanford	
	Barge/rail	All rail	Barge/rail	All rail	Barge/rail	All rail
Offshore to Gulf of Mexico						
Nonoccupational	0.03	0.02	0.04	0.03	0.05	0.03
Occupational	0.09	0.014	0.1	0.02	0.1	0.02
Inland waterways to Mississippi River						
Nonoccupational	0.02	0.01	0.03	0.02	0.03	0.015
Occupational	0.08	0.01	0.08	0.015	0.08	0.015
Rail to water and Gulf of Mexico						
Nonoccupational	0.05	0.01	0.06	0.01	0.06	0.01
Occupational	0.05	0.007	0.06	0.01	0.06	0.01
Total, 35 reactor sites						
Nonoccupational	0.10	0.04	0.13	0.05	0.14	0.06
Occupational	0.22	0.03	0.24	0.05	0.24	0.05
Total	0.32	0.07	0.37	0.10	0.38	0.10

[a] Considers shipments from reactors listed in Table A-39 according to schedule given by Tobin and Meshkov (1985).
[b] Analysis was made only for three potential repository sites.

Table A-41. Summary of the radiological air-release consequences of airborne releases from barge accidents[a]

Accident class[c]	Latent-cancer fatalities[b] Average	Maximum
4	5×10^{-11}	2×10^{-9}
5	6×10^{-6}	2×10^{-4}
6	0.01	0.2

[a] Estimates based on data presented by Unione et al. (1978, Table 6.4).

[b] Based on the assumption that a population dose of 1 man-rem induces 0.0002 latent-cancer fatality plus first- and second-generation genetic effects.

[c] Accident classes from Wilmot et al. (1983).

Table A-42. Summary of the radiological consequences of waterborne releases from barge accidents[a]

Specific dose pathway	Latent-cancer fatalities[b]
Drinking water	1.0
Fresh-water fish	4
Shoreline deposits	0.02
Irrigated crops	0.1
Total of all pathways	5

[a] Estimates based on data presented by Unione et al. (1978, Table 6.16).

[b] Based on the assumption that a population dose of 1 man-rem induces 0.0002 latent-cancer fatality plus first-and second generation genetic effects.

Shipping by barge may be more expensive than the rail mode. Tobin and Meshkov suggest that shipping spent fuel by barge and rail to a repository could cost from $38 to $47 per kilogram of uranium, but these numbers are high because new cost estimates for casks are lower than those used in their study. If values from Table A-35 are substituted, the adjusted cost for barge transportation becomes $27 to $34 per kilogram of uranium. This compares with a range for rail of $13 to $17 per kilogram of uranium, or approximately half the barge and rail cost. The barge-and-rail cost can be reduced by adding more casks to each barge; Tobin and Meshkov assume four railcasks on a barge. It is feasible to ship at least six casks on a barge.

A primary objective of the Tobin and Meshkov study was to determine whether barge transportation is a discriminating factor in site selection. It can be inferred, however, from Table A-40 and from the preliminary estimates of cost per kilogram of uranium shipped that barge transportation will augment the other modes and will be used in special circumstances where the other modes are not available. Since all shipments in the region of the repository site will be completed by rail or truck even if barges are used, no site has a significant advantage because of its proximity to a nearby port. For example, the Richton site may appear to be better than Yucca Mountain because of its proximity to the Gulf of Mexico, but there is no advantage because a shipment to either site must be completed by rail. Similarly, barges on the Columbia River could arrive within about 16 miles of the Hanford site, but this option does not appear reasonable or probable for eastern reactors because of the additional crew exposure, cost, and time required to complete a shipment via the Panama Canal. Administrative concerns, including safeguarding and travel through foreign countries, add to the unlikeliness of this option. As can be seen in Figure A-4, some reactors west of the longitude 100°W could ship to the Hanford site using intermodal transfers. The Trojan plant in Oregon as well as the Humboldt Bay and Diablo Canyon plants in California could possibly ship directly if the proper dock facilities were available. It is not likely that a barge can land at San Onofre in California. Power plants in Arizona and the Rancho Seco plant in California are also not likely to ship by barge because rail shipments would have to be made to a suitable port. In each case, this port is likely to be densely populated, and therefore there is little incentive to use barges.

No additional insight for ranking sites is gained from Table A-40. At this preliminary stage in the evaluation of the barge mode for its feasibility and safety, it is concluded that the barge option is not a discriminating element in comparing sites.

A.11 EFFECT OF THE SECOND REPOSITORY ON TRANSPORTATION ESTIMATES

The analyses that have been discussed to this point (see Section A.8.3) do not explicitly consider the effect of the second repository; however, the siting guideline on transportation requires the second repository to be considered in the cost and risk analyses. A supplementary analysis was performed to predict the expected uncertainty in the results for a single repository when a second repository is added to the waste-management system.

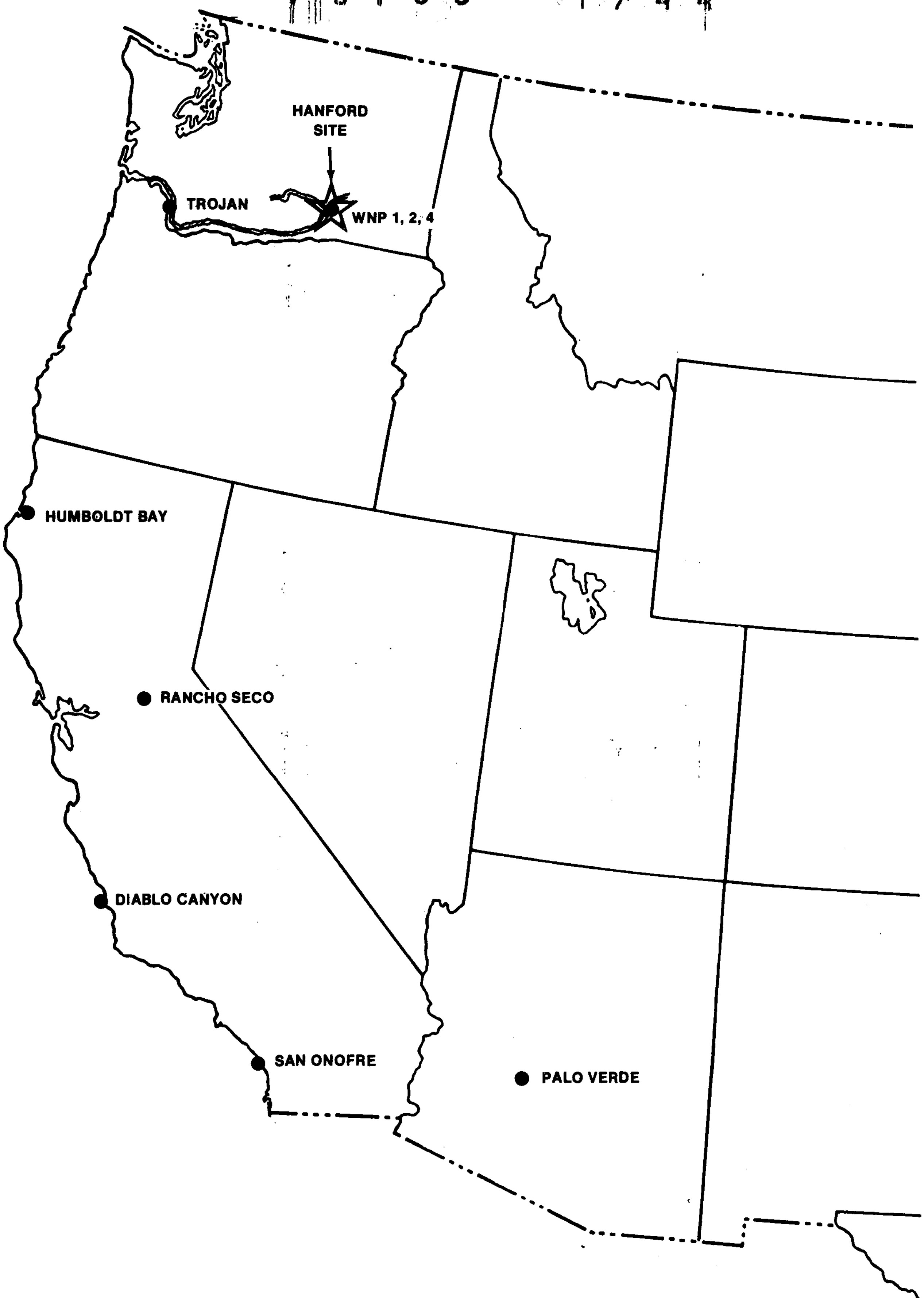

Figure A-4. Reactors west of 100° W longitude.

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A.11.1 SINGLE-REPOSITORY ANALYSES

The impacts resulting from shipments from reactors to the repository have been evaluated for both the authorized system and the improved-performance system.

In the authorized system, spent fuel and high-level waste are shipped directly to the repository. The spent fuel that was assumed to be shipped is generally the oldest fuel, except when a reactor that is running out of storage capacity is given preference. The geographic location of the fuel is not considered.

In the scenarios analyzed for the improved-performance system, similar assumptions were made about the fuel that is shipped, but the fuel is sent first to the MRS facility and then to the repository. Four variations of the improved-performance system were considered. The first two assumed that all of the spent fuel that is received by the repository is routed through the MRS facility. These two variations differ only in the size of the cask assumed to be used for shipments from the MRS facility to the repository (100 and 150 tons). Defense high-level waste is sent directly to the repository; it does not pass through the MRS facility.

Two other variations were generated by taking into account the geographic distribution of some of the fuel. In these variations, about 4,500 MTU of spent fuel from the reactors west of the Rockies is sent to the first repository without passing through the MRS facility. The remaining fuel is preferentially selected by age except for cases where reactors have no storage capacity. These two variations are also distinguishable because two different cask sizes were assumed for each.

None of the variations of the improved-performance system or the authorized system fully consider the geographic distribution of fuel; some do not consider it at all.

A.11.2 LOGIC SUPPORTING THE SUPPLEMENTARY ANALYSIS

If a second repository is introduced into the waste-management system, the spent fuel that will be sent to the first repository can be chosen not only for the age of the fuel but also for the proximity of the fuel to the repository. Logic and the mandate of the Act appear to dictate that fuel closest to the first repository should be shipped to it, with the remainder being shipped to the second repository. When an MRS facility is added to the waste-management system, the ideal fuel selection for the first repository would be the fuel farthest from the second repository (approximately nearest the first repository).

The second repository will enter the system several years after the first. Consequently, its effect on the population of reactors shipping to the first repository will be somewhat reduced because the reactors with storage problems would likely not be restricted from shipment to a more distant first repository as long as their storage problems remained. The supplementary analysis more closely represents a system that simultaneously has two repositories in operation and therefore will manifest the greatest effect of regionality on the transportation impacts.

A.11.3 DESCRIPTION OF SUPPLEMENTARY ANALYSES

Two separate analyses were performed: one that considered the MRS facility and another that did not. For each analysis, two cases were considered: (1) the first repository receives spent fuel from reactors closest to it and (2) the first repository receives spent fuel from reactors farthest from it (Figure A-5). Only Yucca Mountain is shown in Figure A-5; however, similar figures were generated for analyses for each of the five sites nominated as suitable for characterization.

The major assumptions are as follows:

- o The cumulative spent-fuel quantities were assumed to be those of the "midcase" projection by the DOE's Energy Information Administration (EIA).
- o Estimates based on adjusted "great circle" distances.
- o Use of 150-ton casks for shipments from the MRS facility.
- o All spent fuel routed through the MRS facility.
- o Only spent fuel was assumed to be shipped.

The results are presented in Table A-43. Only cask-miles were calculated because cask-miles are a good surrogate measure of transportation costs and risks. Table A-44 contains the percentage variation from the single-repository values. It can be seen that the introduction of a second repository can produce a significant effect on the results for a single-repository analysis.

A.12 CRITERIA FOR APPLYING THE TRANSPORTATION GUIDELINE

The siting guideline on transportation (10 CFR 960.5-2-7) contains a number of terms that are subject to interpretation. These terms are underlined in Table A-45, which is a complete listing of both the favorable and the potentially adverse conditions of the guideline. Terms like "short," "economical," "cuts," and "fills" are clearly open to interpretation. These common terms generally defy the application of accepted objective definitions.

Early in the process of implementing the guideline, it was recognized that a consistent set of criteria was needed to apply the transportation guideline. In September 1984, an ad hoc transportation group was established to deal with transportation issues in the environmental assessments (EAs). The group included a member from the DOE Project Offices representing the three host rocks considered for the first repository and representing substantial expertise in the transportation of radioactive waste. One member had been instrumental in drafting the guideline itself. Before the issuance of the draft EAs, this group developed criteria for applying favorable conditions 1, 2, and 3 and potentially adverse conditions 1 and 3. These

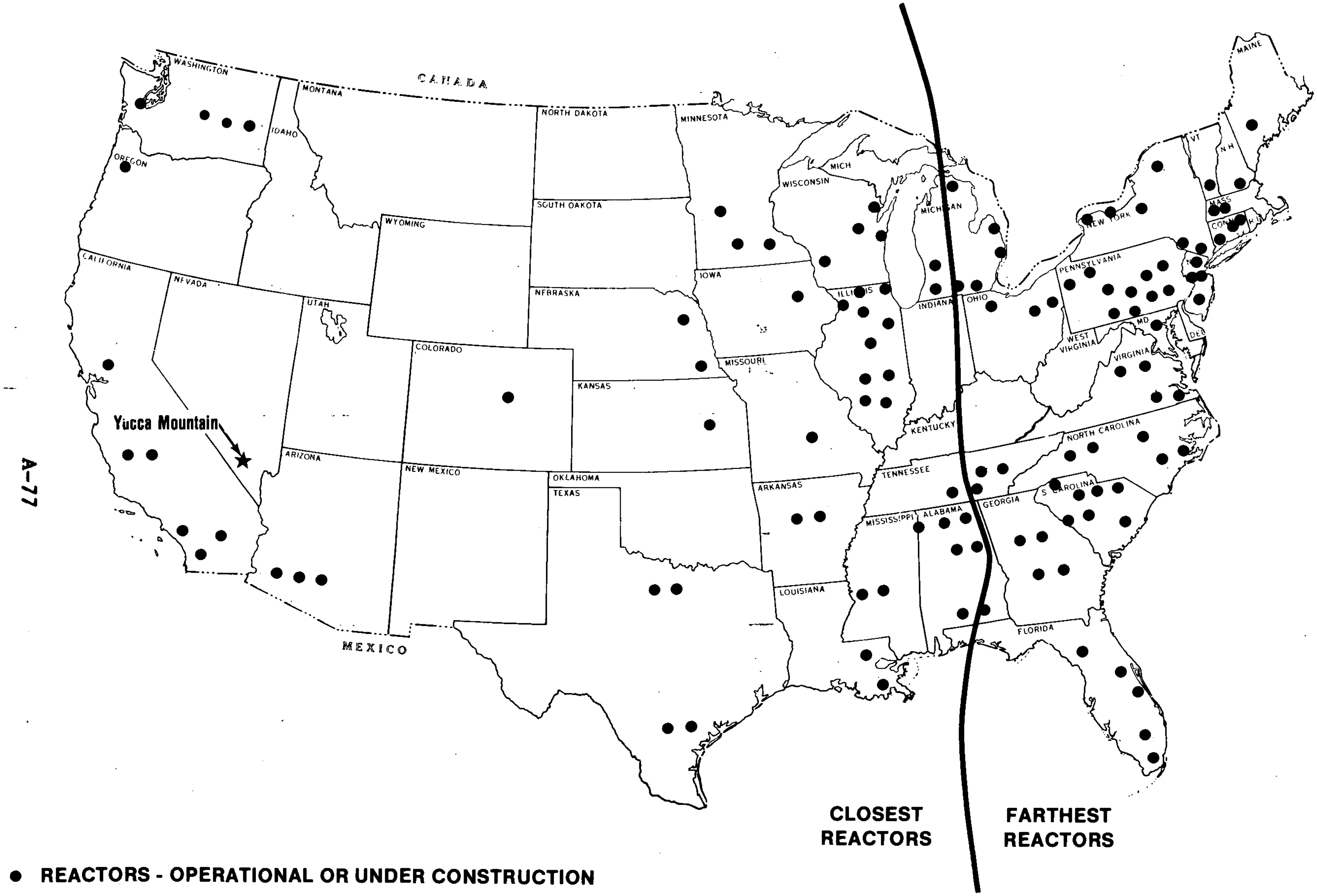

Figure A-5. Analysis of shipping from farthest and closest reactors to Yucca Mountain.

Table A-43. Cask-miles from reactors to potential repository locations with and without an MRS facility[a]
(Millions of cask-miles)

Repository site	Without MRS facility			With MRS facility		
	Closest	EA Analysis	Farthest	Closest	EA Analysis	Farthest
Richton	6.5	11.0	15.3	5.1	9.2	14.0
Deaf Smith	11.6	15.4	18.7	6.8	10.9	15.7
Davis Canyon	14.1	18.8	22.7	7.8	11.9	16.7
Yucca Mountain	17.4	23.2	27.6	11.4	15.6	20.3
Hanford	19.2	24.6	28.9	8.6	12.8	17.5

[a] Estimates based on the shipment of 62,000 MTU of spent fuel.

Table A-44. Percent variation in cask-miles resulting from the introduction of second repository

Repository site	Without MRS facility		With MRS facility	
	Closest	Farthest	Closest	Farthest
Richton	-46	+40	-44	+52
Deaf Smith	-30	+23	-38	+44
Davis Canyon	-29	+22	-34	+40
Yucca Mountain	-29	+21	-27	+30
Hanford	-25	+19	-33	+37

Table A-45. Criteria for applying the transportation guideline

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FAVORABLE CONDITIONS

(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

(iii) Cuts, fills, tunnels, or bridges are not required.

(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.

(v) Such routes bypass local cities and towns.

Criterion

All parts of this favorable condition pertain to the access route to the repository. The access route is the road or railspur that must be constructed to connect existing roads or track with the site. Only one part need be present.

(i) The favorable condition is present if the access route is less than 10 miles long and costs less than $10 million. These criteria are applied to truck and rail routes separately.

(ii) If any part of the access route must be constructed over private land, it is assumed that Federal condemnation will be required, and the favorable condition is not present

(iii) All road or track construction requires cuts and fills. Cuts and fills for generally flat terrain are considered acceptable. The favorable condition is not present if bridges or tunnels are required.

(iv) The favorable condition is present if the access road is constructed over generally flat terrain.

(v) The favorable condition is not present if the access route passes through a highly populated area, as defined in 10 CFR Part 960, Subpart A, or 960.5-2-1(c)(2) (Federal Register, Vol. 49, pp. 47754 and 47763, respectively).

Table A-45. Criteria for applying the transportation guideline (Continued)

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(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.

Criterion

This favorable condition pertains to that segment of existing track between the outer end of the access route and the nearest State, Federal, or interstate highway and the nearest mainline railroad that does not require upgrading or repair. This segment of road or track should be no longer than 10 miles and cost no more than $10 million.

(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.

Criterion

This distance refers to the length of the road or track between the outer end of the access route and the nearest State, Federal, or interstate highway or the nearest mainline railroad. This distance should be no more than 30 miles. Distance to a waterway is not considered because a barge shipment would have to offload onto a railroad.

(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

Criterion

All sites have at least one railroad interchange point at the point where the site spur joins the mainline. All other interchanges within 125 miles of the site will be counted. The site with the fewest interchanges will be considered to have the favorable condition present.

(5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.

Criterion

All sites will be compared; only one site will have the favorable condition present.

Table A-45. Criteria for applying the transportation guideline (Continued)

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(6) Availability of regional and local carriers--truck, rail, and water--which have the capability and are willing to handle waste shipments to the repository.

Criterion

This favorable condition is present if any carrier--truck, rail, or water--is available within the minimum transportation study area.

(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.

Criterion

This favorable condition will be addressed as explained in Appendix C.

(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

Criterion

Any evidence that emergency-response plans, procedures, and capabilities exist will be favorable. Evidence for all of these is required for a finding that the favorable condition is present.

(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

Criterion

The repository activity is significantly disrupted if it is not able to meet its annual acceptance rate.

Table A-45. Criteria for applying the transportation guideline (Continued)

POTENTIALLY ADVERSE CONDITIONS

(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

Criterion

An expensive access route is considered to be one that costs more than $10 million.

(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.

Criterion

This potentially adverse condition is present if the terrain over which the access route must pass is not generally flat and if the access route must cross a river or lake.

(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

Criterion

This potentially adverse condition is present if a significant reconstruction or upgrading of a truck or rail route costs more than $10 million. This criterion is applied separately to truck and rail routes.

(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Criterion

Examples of local conditions that are potentially adverse are proximity to a bombing range, extreme costs, and despoiling of the environmental and aesthetic qualities of pristine land.

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criteria were applied during the ranking process documented in Chapter 7 of the draft EAs.

The process by which the criteria were developed relied heavily on the collective transportation expertise of the ad hoc group. Rules-of-thumb were often used to make estimates in the context of indefinite terms. For example, the cost of a mile of new highway or railroad track is often assumed to be $1 million when the route traverses flat terrain. Such an estimate might be used when much additional information is not available. The application of such rules, experience, and informed judgment allowed more-definitive criteria to be developed while considering the requirement to judge transportation conditions in the context of "comparable siting options." In other words, the criteria values were developed by fully considering the range and distribution of values for all of the five sites nominated as suitable for characterization.

The comments on the draft EAs noted other inconsistencies in the findings reported for the transportation guideline, particularly for the conditions that contain the term "regional". The DOE then decided to develop criteria for all of the conditions in the transportation guideline. Through repeated discussions with the ad hoc committee members, the final criteria presented in Table A-45 were promulgated in August 1985. Again, the process of criteria development relied on the judgment of the transportation ad hoc group.

A.13 COMMON QUESTIONS REGARDING TRANSPORTATION

A.13.1 PRENOTIFICATION

Many States wish to be notified in advance of certain radioactive-waste shipments.

Whether prenotification results in an increase in safety is the subject of considerable discussion among Federal regulatory agencies and State and local governments. Currently, the NRC, under Congressional mandate, requires NRC licensees to notify States in advance of spent-fuel and certain radioactive-waste shipments (10 CFR 71.97 and 73.37(f)). The DOT requires postnotification of shipments (49 CFR 173.22(d)). In an effort to understand the issue and to gauge the efficacy of the NRC regulation, the DOE sponsored a study (Pellettieri and Welles, 1985). Currently, the DOE and the DOT have completed a joint study that surveyed the State, local, and facility notification requirements for hazardous materials (Dively et al., 1985).

The DOE currently provides State officials with generic notification of its shipments of radioactive material. This notification reviews the type and quantity of shipments but does not designate the time and the date of shipment. For current shipments in support of the OCRWM research and development program, the DOE is supplementing this generic notification with courtesy communications to an appropriate officer of each State through which the shipment will pass. In light of the number of spent-fuel shipments to repositories, the DOE will evaluate its current procedures for tracking radioactive-waste shipments and consider a number of additional options. For example, an effective real-time shipment-tracking system may be a preferable alternative to prenotification. Decisions will be based on the best technology available and applicable laws and regulations in use at the time of shipment to a waste-management facility.

A.13.2 EMERGENCY RESPONSE

Emergency response to a transportation accident involving radioactive material is another concern of State and local officials.

State and local jurisdictions have the primary responsibility for emergency response to incidents occurring in connection with all hazardous materials, including spent-fuel shipments. Federal assistance can be provided in many ways, however. For example, the DOE will make available from its resources such radiological advice and assistance as is requested and appropriate to protect public health and safety and to cope with radiological hazards. DOE personnel will respond to requests from NRC licensees; Federal, State, and local authorities; and private persons or companies, including carriers. Assistance can be obtained from any one of eight DOE regional centers, which are capable of responding to radiological incidents on a 24-hour basis. Requests for aid are handled directly through the DOE regional centers or through an emergency clearing house called CHEMTREC (Chemical Transportation Emergency Center) that is sponsored and funded by the chemical industry. The DOE offices, when requested, will provide radiation assistance teams.

For States hosting facilities developed under the Act, the DOE will seek to negotiate written agreements that can address assistance and funding for emergency-response preparations. In other States, funding or assistance in lieu of funding (e.g., training courses, equipment, etc.) will continue to be available through the Federal Emergency Management Agency (FEMA) or other Federal agencies. Examples of the type of assistance already provided by the Federal Government are the emergency-response workshops for first responders sponsored by the DOE at various locations in the country each year as part of its compliance training program.

The FEMA has coordinated the development of the interim Federal Radiological Emergency Response Plan (Federal Register, Vol. 49, p. 35896). The interim plan outlines procedures to be taken in the event of nuclear accidents, including those involving the transportation of radioactive waste, and is designed to provide coordinated Federal response in support of State and local governments. Under the plan, State and local governments have the primary responsibility for responding to emergencies; Federal technical assistance is provided on request. In addition, the FEMA has published interim Guidance for Developing State and Local Radiological Emergency Response Plans and Preparedness for Transportation Accidents (FEMA, 1983). This guidance, which is currently being revised, provides a basis for State and local governments to develop emergency plans and improve emergency preparedness for transportation accidents involving radioactive materials.

A.13.3 HIGHWAY ROUTING

A.13.3.1 Highway routing regulations

The routing of radioactive-waste shipments is a primary concern of State, local, and tribal officials. On January 19, 1981, the DOT by its authority under the Hazardous Materials Transportation Act, published a final rule governing the highway routing of radioactive materials. Designated HM-164, this rule has been codified as 49 CFR Parts 171, 172, 173, and 177. The DOE will, of course, comply with all DOT regulations.

According to HM-164, highway carriers of "highway route controlled quantity radioactive materials" (e.g., spent nuclear fuel) are required to use "preferred routes." A preferred route consists of an interstate highway, including the use of interstate beltways or bypasses when available to avoid city centers, or alternative routes that are designated by a State routing agency (which includes the appropriate authorities of Indian Tribes). State-designated alternative routes must be selected in accordance with DOT guidelines for selecting preferred highway routes (DOT, 1984) or an equivalent routing analysis that adequately considers the overall risk to the public.

The DOT stated that it followed three basic concepts in devising a highway-routing framework for radioactive materials:

1. Route selection should be based on some valid measure of reduced risk to the public.

2. Uniform and consistent rules for route selection are needed from both a practical and a safety standpoint.

3. Local views should be carefully considered in routing decisions because routing is a site-specific activity unlike other transportation controls, such as marking and packing (Federal Register, Vol. 46, p. 5299).

The DOT's approach to routing acknowledges that public policy for the routing of radioactive materials should be based on a consideration of the overall risk involved in transporting such materials. The risk depends on such factors as accident rates, total travel time, traffic patterns, population density, road conditions, time of travel, and driver training. Further, the DOT recognized the need to balance local and national interests in routing decisions while providing for uniformity and consistency of transportation regulations. With regard to the acknowledged need to provide for local input in routing decisions, the DOT provided for the designation of alternative routes to interstate highways by State routing agencies in consultation with affected localities, neighboring States, and Indian Tribes and in accordance with DOT guidelines, to ensure the consideration of all impacts and continuity of designated routes.

Carriers of spent fuel may deviate from a preferred route under the following three circumstances:

1. Emergency conditions that would make continued use of the preferred route unsafe.

2. To make necessary rest, fuel, and vehicle-repair stops.

3. To the extent necessary to pick up, deliver, or transfer a large-quantity package of radioactive materials (49 CFR 177.825(b)(2)).

HM-164 has numerous other provisions designed to ensure the safe highway shipment of radioactive materials. These include the requirement for the provision of written route plans to the shipper and specific driver-training requirements, which include knowledge of procedures to be followed in an accident or other emergency.

There are several methods by which the DOE can support the highway-routing efforts of the States and the DOT. On request, the DOE will assist the States as practicable in the evaluation and determination of State-designated alternative routes. The DOE, as the shipper of record, will continue to notify its carriers of the State-designated alternative routes and will instruct that these routes be used during all shipments. Moreover, the carrier will be instructed that all safety and routing requirements must be met and that lack of compliance will result in appropriate sanctions, including the potential suspension of carriers (41 CFR 109-40.103-1). Federal and State reports of carrier performance, postnotification of routes, and DOE tracking of actual shipments will provide mechanisms by which operations can be monitored. In addition to diligent and consistent observance of these currently available procedures, the DOE will continue to coordinate with the States concerning the routing of any highway route controlled quantities (49 CFR 173.403) of radioactive materials shipped by the DOE.

A.13.3.2 State and local ordinances

As discussed in the preceding section, the DOT derives its authority to regulate hazardous-materials transportation principally from the Hazardous Materials Transportation Act (HMTA). The HMTA (Section 112(a)) preempts "...any requirement of a state or political subdivision thereof, which is inconsistent with any requirement set forth in [the HMTA] or regulations issued under [the HMTA]." Thus, State or local actions are not necessarily precluded; only those that are "inconsistent" are preempted. The DOT can, however, grant an exemption from this blanket preemption provision to allow an inconsistent State or local requirement to remain in effect. Such an exemption can be granted if, mainly because of local considerations, the requirement (1) affords an equal or greater level of protection to the public than is afforded by the requirements of the HMTA or of regulations issued under the HMTA and (2) does not unreasonably burden commerce.

In its general discussion of the highway-routing rule, the DOT notes its conclusion that "the public risks in transporting [radioactive] materials by highway are too low to justify the unilateral imposition by local governments of bans and other severe restrictions on the highway mode of transportation" (<u>Federal Register</u>, Vol. 46, p. 5299).

Appendix A to 49 CFR Part 177 delineates DOT policy regarding the consistency of State and local rules with DOT highway-routing requirements for the purpose of advising State or local governments how they can exercise their responsibilities with respect to the regulation of motor carriers. The DOT generally regards State and local requirements to be inconsistent if they--

- Prohibit the transportation of large-quantity radioactive materials by highway between any two points without providing an alternative route for the duration of the prohibition.
- Conflict with NRC or DOT physical-security requirements.
- Require additional or special personnel, equipment, or escort.
- Require additional or different shipping paper entries, placards, or other hazard-warning devices.
- Require filing route plans or other documents containing information that is specific to individual shipments.
- Require prenotification.
- Require accident or incident reporting other than as immediately necessary for emergency assistance.
- Unnecessarily delay transportation.

A.13.4 RAILROADS

A.13.4.1 Railroad routing

There are no regulatory requirements for the routing of rail shipments. Rail-shipment routes depend largely on the railroad to which the shipment is originally consigned and how that (and each successive) railroad handles interconnections with other railroads.

A.13.4.2 Rail regulations

Several government agencies perform inspection-and-enforcement activities to promote the safe transportation of radioactive materials on the nation's railroads. Since rail is a predominantly interstate mode of transportation, the Federal Government has long been considered the entity best equipped to develop, promulgate, and enforce a uniform set of safety regulations for the transportation of hazardous materials by rail.

The safety and safeguards regulations for shipments of radioactive material by rail, in many cases, are the same as those for highway shipments. The NRC has issued general routing guidelines for rail shipments of spent fuel, which are included in its physical-protection requirements that were promulgated to guard against acts of sabotage for both rail and truck spent-fuel shipments. The DOT has issued specific rules limiting both the number and the duration of rail stops and designating the placement of cars carrying spent fuel in the makeup of the train. In addition, there are standards for track quality and other operating features of importance to safety of rail transport.

Shippers who prepare material for rail transportation are required to comply with DOT regulations found in 49 CFR Part 173 before offering any hazardous material shipment to a carrier. The responsibilities of rail carriers of radioactive waste are outlined in DOT regulations 49 CFR Part 174. In accepting a shipment, the carrier inspects it visually to ascertain that the hazardous material is not leaking, that specific rail equipment (air and handbreaks, journal boxes, and trucks) is working properly, and that appropriate placards are provided. The carrier cannot accept packages that are leaking or damaged. In addition to the DOT requirements, rail companies inspect railcars periodically to ensure that they are mechanically safe for operation. In particular, certain equipment is routinely inspected at interchange points by the carrier.

Carrier operations are also subject to DOT regulations covering safety enforcement procedures, track safety standards, and accident-reporting procedures. Under the conditions of 49 CFR 171.15 and 171.16, the carrier must notify the DOT immediately of any unintentional release of a hazardous material during the course of transportation and must submit a written hazardous materials incident report to DOT within 15 days of such an event.

Although jurisdiction over the transport of radioactive waste by rail is vested primarily in the Federal Government, States and local governments that wish to assume specific responsibilities in this area also have a role. The Federal Rail Safety Act (45 U.S.C. 434) directs that a State may enforce its own railroad safety regulation provided that the State regulation is (1) consistent with Federal regulations, (2) necessary to eliminate or reduce an essentially local safety hazard, and (3) not a burden on the free flow of interstate commerce.

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) is investigating means for facilitating a cooperative effort among affected Federal and State agencies and the railroad industry in forging shipping arrangements that are safe, efficient, and equitable. There appears to be a strong willingness by all affected parties to work toward this goal.

The DOE will reinforce the DOT's and the NRC's inspection-and-enforcement activities through the establishment of a comprehensive quality-assurance and quality-control program to address each aspect of the transportation process, including the integrity of the shipping casks and the procedures for handling the casks. The quality-assurance program will implement systematic procedures designed to ensure and provide demonstrable evidence that program goals, such as safety, reliability, and maintainability, are achieved in a cost-effective manner.

A.13.4.3 Dedicated trains

The use of "dedicated trains" involves the designation of specific equipment (locomotives, cask cars, buffer cars, and cabooses) for the use of a particular commodity between fixed origin and destination points. In many respects, it is similar to the "sole-use" vehicle that is commonly employed by motor carriers for specific commodities (one example is the transportation of bulk, low-specific-activity radioactive material).

Special arrangements to expedite the movement of dedicated trains can be made among railroads. For example, the equipment "dedicated" for sole use may be owned by the originating carrier. This equipment could be used for the full length of the move. There may be no switching or interchange with other carriers at terminals along the route. After delivery, the empty cars are returned to the origin for the next movement, possibly under the same expedited process as the loaded train. The originating carrier and the carriers that own and operate the rail lines to be used by the dedicated train would agree on the apportionment of revenues among themselves for the entire move.

A.13.5 INSURANCE COVERAGE FOR TRANSPORTATION ACCIDENTS

The Price-Anderson Act of 1957 (42 U.S.C. Sections 2014 and 2210, as amended) provides extensive liability coverage for damages suffered by the public in the event of nuclear accidents at certain facilities (which include commercial nuclear power reactors and DOE contractor-operated facilities) or accidents that occur in the course of transportation to or from such facilities. Liability coverage extends to all potentially responsible parties (except, in some instances, the Federal Government, whose liability would be covered under the Federal Tort Claims Act) and is not limited to parties who actually purchase insurance or enter into indemnity agreements with the Federal Government.

State law is generally used to determine liability and the extent of damages in the event of a nuclear incident; the Price-Anderson Act in turn establishes a system for paying for those damages. The Act places restrictions on the use of State law in the event of an "extraordinary nuclear occurrence" (ENO) at certain facilities—an occurrence that involves substantial offsite releases of radiation and is likely to result in substantial offsite damages to persons or property. When the Federal Government determines that an extraordinary nuclear occurrence has occurred, certain defenses available under State law must be waived. One waiver requires the imposition of strict liability, without proof of negligence on the part of any responsible party. Defenses related to governmental immunity are also waived. The Price-Anderson Act further declares that in the event of an extraordinary nuclear occurrence, defenses based on statutes of limitations will be waived if a suit is brought within "three years from the date that the claimant first knew, or reasonably could have known, of his injury or damage and the cause thereof, but in no event more than twenty years after the date of a nuclear incident." A State statute of limitations that allows a greater period of time for filing suit would remain in effect.

Another important feature of the Price-Anderson Act is the monetary limitation on liability. To the extent that damages exceed the amount of coverage required by the Act, all responsible parties are relieved of further liability; Congress is then required to investigate the incident and take appropriate action.

The Price-Anderson Act provides for liability coverage through a system of private insurance and government indemnity. Under the Act's private insurance system, utility owners of large NRC-licensed commercial nuclear power reactors are required to maintain the maximum amount of insurance available from private sources (currently, $160 million). Should claims arising from a nuclear incident (related to the activities of such NRC licensees) exceed the amount of primary insurance, all licensees of large nuclear power reactors would be assessed up to $5 million per reactor. With 98 large reactors now licensed to operate (as of January 1986), a second layer of coverage is provided in the amount of $490 million. Both forms of coverage provide a total of $640 million in the event of a serious nuclear incident at a nuclear power plant or an incident occurring in the course of transportation to or from such a facility.

The Price-Anderson Act also authorizes the DOE to enter into indemnity agreements with its contractors for activities, under contract and conducted for the benefit of the United States, that involve "the risk of public liability for a substantial nuclear incident." The indemnity coverage under such contracts provides that, in the event of a nuclear incident arising out of, or in connection with, a contractual activity, the contractor and any other person who may be liable would be indemnified by the DOE, up to the statutory limit of $500 million. Indemnity coverage under DOE agreements further extends to nuclear incidents arising in the course of transportation to or from contractor locations. The DOE does not require contractors to carry additional liability insurance because the cost of any such insurance would be passed on to the DOE. Since the enactment of the Nuclear Waste Policy Act, the DOE has indicated that indemnity agreements based on the Price-Anderson Act will be included in its contracts for the operation of any DOE facility associated with the waste-management program (e.g., a geologic repository and MRS facility, if approved by Congress). Under the indemnity agreement, the DOE is to indemnify the facilities' operating contractor and any other person who may be liable for a nuclear incident arising out of, or in connection with, radioactive waste management. Coverage for waste-management activities would extend to transportation to or from a waste-management facility.

Congressional review of the Price-Anderson Act is now under way and is expected to be completed by 1987, when the Act will expire unless reauthorized. The DOE has offered recommendations to Congress pertaining to the Act's contractor indemnity system and the application of that system to activities conducted under the Nuclear Waste Policy Act. Such recommendations include the following:

- Extended liability coverage. While a limitation on liability is supported, the DOE has recommended that the extent of coverage under DOE indemnity agreements be comparable to that afforded by large commercial utilities.

- <u>Explicit coverage of activities conducted under the Nuclear Waste Policy Act</u>. While the DOE believes that the present language of the Price-Anderson Act is sufficient to permit indemnification coverage for nuclear waste operations, explicit coverage under the Act is supported.

- <u>Application of ENO provisions to waste-management activities</u>. The DOE supports the extension of the Act's ENO provisions, with the related waiver of defenses, to incidents connected with the transportation, storage, and disposal of civilian and defense high-level waste.

- <u>Source of funding</u>. The DOE supports the provision of liability coverage for waste-management activities conducted under the Nuclear Waste Policy Act through expenditures of the Nuclear Waste Fund (which in turn is financed through fees paid by the generators and owners of radioactive waste).

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Appendix B

AVAILABILITY OF REFERENCES

Appendix B

AVAILABILITY OF REFERENCES

B.1 REFERENCES CITED IN ALL EAs

The references cited in all of the draft and the final environmental assessments (EAs) are available for public review in DOE reading rooms at the following locations.

U.S. Department of Energy
Public Reading Room
FOI, Room 1E-190
1000 Independence Avenue, S.W.
Washington, DC 20585

Albuquerque Operations Office
National Atomic Museum
Kirkland Air Force Base East
Albuquerque, NM 87116

Chicago Operations Office
9800 South Cass Avenue
Argonne, IL 60439

Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401

Nevada Operations Office
2753 South Highland Drive
Las Vegas, NV 89109

Oak Ridge Operations Office
Federal Building
Oak Ridge, TN 37830

Richland Operations Office
Federal Building
Richland, WA 99352

San Francisco Operations Office
Wells Fargo Building
1333 Broadway
Oakland, CA 95612

Savannah River Operations Office
Savannah River Plant
Aiken, SC 29801

B.2 REFERENCES CITED IN THE EA FOR THE BASALT (HANFORD) SITE

The references cited in the EA for the Hanford site are available for public review at the following locations:

Idaho

Boise Public Library and
Information Center
715 Capitol Boulevard
Boise, ID 83702

Lewiston City Library
428 Thain Road
Lewiston, ID 83501

Coeur D'Alene Public Library
703 Lakeside Avenue
Coeur D'Alene, ID 83814

University of Idaho Library
(Federal Depository)
Moscow, ID 83843

Oregon

Portland State University
(Federal Depository)
Bradford Price Millar Library
934 Southwest Harrison
Portland, OR 97207

Umatilla County Library
214 North Main Street
Pendleton, OR 97801

Washington

University of Washington Libraries
M-171 Library, FM-25
Seattle, WA 98195

Central Washington University
D and 11 Street
Ellensburg, WA 98926

Washington State Library
(Federal Depository)
Temple of Justice
Olympia, WA 98504

Pasco Public Library
1320 West Hopkins
Pasco, WA 99301

Seattle Public Library
1000 Fourth Avenue
Seattle, WA 98104

Fort Vancouver Regional Library
1007 East Mill Plain Boulevard
Vancouver, WA 90663

Prosser Public Library
902 Seventh Street
Prosser, WA 99350

State of Washington Dept. of Ecology
Office of High-Level Nuclear Waste Management
Reference Center
5826 Pacific Avenue
Lacey, WA 98504

Eastern Washington University
John F. Kennedy Memorial
Cheney, WA 99004

Washington State University Library
Holland Library, Room 221
Library Road
Pullman, WA 99164-5610

Mid-Columbia Library
405 South Dayton
Kennewick, WA 99336

Richland Public Library
Swift and Northgate
Richland, WA 99352

Spokane Public Library
Comstock Building Library
West 906 Main Avenue
Spokane, WA 99201

Walla Walla Public Library
238 East Adler
Walla Walla, WA 99362

U.S. Department of Energy
Reading Room, Hanford Science Center
825 Jadwin Avenue
Richland, WA 99352

Yakima Valley Regional Library
102 North Third Street
Yakima, WA 98901

B.3 REFERENCES CITED IN THE EA FOR THE SALT SITES

The references cited in the EAs for the Davis Canyon, Utah, Deaf Smith, Texas, and Richton, Mississippi, are available for public review at the following locations:

Louisiana

Minden Nuclear Waste Information Office
221 Main Street
Minden, LA 71005

Bienville Parish Library
604 South Maple
Arcadia, LA 71001

Webster Parish Library
521 East and West Streets
Minden, LA 71005

Mississippi

Richton Nuclear Waste Information Office
103 Dogwood
Richton, MS 39476

Harrison County Library
14th Street and 21st Avenue
Gulfport, MS 39510

Pine Forest Regional Library
Main Street
Richton, MS 39476

Jackson-George Regional Library
3214 Pascagoula Street
Pascagoula, MS 39567

Jackson Metropolitan Library
301 North State Street
Jackson, MS 39201

Harriette Person Memorial Library
College Street
Port Gibson, MS 39150

Hattiesburg Public Library
723 Main Street
Hattiesburg, MS 39401

Laurel-Jones County Public Library
530 Commerce Street
Laurel, MS 39440

Jones County Junior College Library
Front Street
Ellisville, MS 39437

Texas

Deaf Smith County Library
211 East Fourth Street
Hereford, TX 79045

Rhoads Memorial Library
103 Southwest Second Street
Dimmitt, TX 79027

Swisher County Library
127 Southwest Second Street
Swisher County Memorial Building
Tulia, TX 79088

Gabie Betts Burton Memorial Library
217 S. Karney St.
Clarendon, TX 79226

Canyon Public Library
301 16th Street
Canyon, TX 79015

Austin Public Library
800 Guadalupe Street
Austin, TX 78768

Texas (continued)

Amarillo Public Library
413 East Fourth Street
Post Office Box 2172
Amarillo, TX 79189

Texas Nuclear Waste Programs Office
Sam Houston Office Building, Room 204
200 East 14th Street
Austin, TX 78711

Tulia Nuclear Waste Information Office
Griffith Estate Building
100 S.E. Second
Tulia, TX 79088

University of Texas General Library
Post Office Box P
Austin, TX 78712

Hereford Nuclear Waste Information Office
115 East First Street
Hereford, TX 79045

Utah

Moab Nuclear Waste Information Office
471 South Main Street No. 3
Moab, UT 84532

Monticello Nuclear Waste Information Office
San Juan County Courthouse
117 South Main Street, Room 12
Monticello, UT 84535

Grand County Public Library
25 South First Street East
Moab, UT 84532

Grand County High School Library
300 South 100 East
Moab, UT 84532

San Juan County Library
266 North Main Street
Monticello, UT 84535

Monticello High School Library
Media Center
55 North Second Street West
Monticello, UT 84535

San Juan County Library
50 West First Street South
Blanding, UT 84535

Mesa County Public Library
530 Grand Avenue
Grand Junction, CO 81501

Salt Lake City Public Library
2197 East 7000 South
Salt Lake City, UT 84121

University of Utah
Marriott Library
Salt Lake City, UT 84112

B.4 REFERENCES CITED IN THE EA FOR THE TUFF SITE

The references cited in the EA for the Yucca Mountain site are available for public review at the following locations:

Amargosa Valley Community Library
Star Route 15
Box 40-T
Amargosa Valley, NV 89020

Beatty Community Library
4th and Ward
P.O. Box 128
Beatty, NV 89003

Clark County Library
1401 E. Flamingo
Las Vegas, NV 89109

Lincoln County Library
P.O. Box 330
Pioche, NV 89043

Nevada State Library
401 N. Carson
Capitol Complex
Carson City, NV 89710

University of Nevada at Las Vegas
James R. Dickinson Library
4505 Maryland Parkway
Las Vegas, NV 89154

United States Department of Energy
Nevada Operations Office
Public Reading Room
2753 South Highland
Las Vegas, NV 89109

Law Library
Nye County Courthouse
P.O. Box 393
Tonopah, NV 89049

Nevada Legislative Council Bureau
Research Library
Legislative Building
Capitol Complex
Carson City, NV 89710

Northern Nevada Community College
Learning Resource Center
901 Elm Street
Elko, NV 89801

University of Nevada at Reno
Getchell Library
Reno, NV 89557

Washoe County Library
301 Center Street
Reno, NV 89502

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