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Volume 2 of 3

Nuclear Waste Policy Act
(Section 112)

Environmental Assessment

Richton Dome Site, Mississippi

Volume II

May 1986

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

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Chapter 6

SUITABILITY OF THE RICHTON DOME SITE FOR SITE CHARACTERIZATION AND FOR DEVELOPMENT AS A REPOSITORY

The Nuclear Waste Policy Act of 1982 (the NWPA) (42 USC Sections 10101-10226) requires the environmental assessment to include a detailed statement of the basis for nominating a site as suitable for characterization. This detailed statement is to be an evaluation of site suitability under the DOE siting guidelines; the evaluation will be the basis for the comparison of sites reported in Chapter 7. Such an evaluation for the Richton Dome site is presented in Sections 6.2, 6.3, and 6.4 of this chapter, and is based in part on impacts associated with the reference repository design. Given the considerations and conclusions in Section 5.1 and Table 5-1, the evaluation would not change if based on the Mission Plan repository concept. A brief explanation of the siting guidelines--their format, structure, and implementation--is given in Section 6.1.

6.1 THE DOE SITING GUIDELINES

As directed by Section 112 of the NWPA, the DOE has developed general guidelines for siting geologic repositories. These guidelines have been published as 10 CFR Part 960 (DOE, 1984). They are to be used in the remaining steps of the site-selection process for the first repository: the nomination of at least five sites as suitable for characterization, the recommendation of not less than 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 guidelines, postclosure guidelines, and preclosure guidelines. 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 the operation of the repository before it is closed. These are the considerations important in protecting the public and the repository workers from exposures to radiation during repository operations. They are also the most important considerations in protecting the quality of the environment and in mitigating socioeconomic impacts, because most of the environmental and socioeconomic effects of a repository will occur during its construction and operation.

As explained in the supplementary information preceding the guidelines, both the postclosure and the 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 promulgated by the U.S. Environmental Protection Agency (EPA) and released as 40 CFR Part 191 (EPA, 1985) and the criteria promulgated by the Nuclear Regulatory Commission (NRC) in 10 CFR Part 60 (NRC, 1983). 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 some characteristics of the site and some 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 the requirements for one or more of these system elements.

Both 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 be able to reveal the relative potential of those sites to meet the qualifying conditions.

Disqualifying conditions are stated 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 predict 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 for that 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 may 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 systems 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 guidelines requires for disqualifying and qualifying conditions. Using the term "apply" to mean to evaluate a condition and make a finding of compliance, this appendix specifies how the guidelines are to be applied at the principal decision points of the siting process: (1) site identification as potentially acceptable, (2) nomination as suitable for characterization or recommendation for characterization, and (3) recommendation for development as a repository. In particular, this appendix specifies the types of findings that are to result from the applications 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 both 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, which is a higher level finding requiring greater confidence and more extensive data to support it, 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 is stated to mean 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 Level 1 finding must be made for each disqualifying condition, and at least a 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 currently existing for the site or conservative assumptions when the existing data are inadequate for the identification. ("Conservative" assumptions are assumptions that minimize the possibility that later findings will prove the assumptions to be wrong.) In order for a favorable condition to be claimed as "present," it is necessary for the existing data to clearly support that conclusion. Otherwise, the favorable condition is stated to be "not present." Similarly, a potentially adverse condition is stated to be "present" unless the existing 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 guidelines.

6.1.3 Division of the Guidelines into Categories

The NWPA requires two separate 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 two 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 NWPA. The NWPA defines site characterization essentially as activities undertaken to establish the geologic conditions at a candidate site, including borings, surface excavations, the sinking of exploratory shafts, and underground testing at repository depth.

Therefore, in accordance with this definition, the guidelines requiring site characterization as a prerequisite to their application are mainly those that contribute to establishing the geologic conditions at a site. The guidelines in this category are concerned predominantly with subsurface conditions, and most of them are postclosure guidelines. Section 6.3 presents the evaluations of the site against the guidelines in this category. The information required to establish compliance with these guidelines will be obtained during site characterization.

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

Table 6-1 lists the guidelines in each category and shows the levels of findings that were made in accordance with Appendix III of the guidelines.

6.1.4 Formats 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 the 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 the uncertainties in the data. Each favorable, potentially adverse, and disqualifying condition is then discussed in turn; 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 at one of the levels specified by Appendix III of the guidelines (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 none of these conditions appears in the System Guidelines.

The conclusions drawn in these presentations are different in Section 6.2 and in Section 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.

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

In this section suitability of the Richton Dome site for development as a repository under guidelines not requiring site characterization is discussed. Site suitability factors that fall into this category are addressed by the following System Guidelines and corresponding Technical Guidelines:

1. 10 CFR 960.4-1(a) Postclosure: System Isolation Requirements

   - 10 CFR 960.4-2-8-2 Site Ownership and Control

2. 10 CFR 960.5-1(a)(1) Preclosure: Radiological Safety

   - 10 CFR 960.5-2-1 Population Density and Distribution
   - 10 CFR 960.5-2-2 Site Ownership and Control
   - 10 CFR 960.5-2-3 Meteorology
   - 10 CFR 960.5-2-4 Offsite Installations and Operations

3. 10 CFR 960.5-1(a)(2) Preclosure: Environment, Socioeconomics, and Transportation

   - 10 CFR 960.5-2-5 Environmental Quality
   - 10 CFR 960.5-2-6 Socioeconomic Impacts
   - 10 CFR 960.5-2-7 Transportation.

The evaluation process is not meant to imply that sufficient information is available at this time to fully evaluate compliance of the site with the intent of these guidelines. The distinction is based solely on the definition of site characterization (see Section 6.1).

Table 6-1. Categorization of Guidelines and Findings Based on Application of the Disqualifying and Qualifying Conditions

Guideline		Level of Finding: Disqualifying Condition	Level of Finding: Qualifying Condition
	Guidelines Not Requiring Site Characterization		
960.4-2-8-2	Site Ownership and Control	--	3
960.5-2-1	Population Density and Distribution	1	3
960.5-2-2	Site Ownership and Control	--	3
960.5-2-3	Meteorology	--	3
960.5-2-4	Offsite Installations and Operations	1	3
960.5-2-5	Environmental Quality	1	3
960.5-2-6	Socioeconomic Impacts	1	3
960.5-2-7	Transportation	--	3
960.5-1	Preclosure System Guideline		
	(a)(1) Preclosure Radiological Safety	--	3
	(a)(2) Environment, Socioeconomics Transportation	--	3
	Guidelines Requiring Site Characterization		
960.4-2-1	Geohydrology	1	3
960.4-2-2	Geochemistry	--	3
960.4-2-3	Rock Characteristics	--	3
960.4-2-4	Climatic Changes	--	3
960.4-2-5	Erosion	--	3
960.4-2-6	Dissolution	1	3
960.4-2-7	Tectonics	1	3
960.4-2-8-1	Natural Resources	1	3
960.4-1	Postclosure System Guideline	--	3
960.5-2-8	Surface Characteristics	--	3
960.5-2-9	Rock Characteristics	1	3
960.5-2-10	Hydrology	1	3
960.5-2-11	Tectonics	1	3
960.5-1	Preclosure System Guideline		
	(a)(3) Ease and Cost of Siting, Construction, Operation, and Closure	--	3

The evaluation of site characteristics with respect to the Technical Guidelines is presented in Section 6.2.1. In Section 6.2.2, the associated sets or clusters of technical factors are evaluated in the system context of their interactive and integrated contribution to satisfying regulatory requirements as defined in the System Guidelines.

6.2.1 Technical Guidelines

This section addresses those Technical Guidelines that do not require site characterization as a prerequisite for their application. These Technical Guidelines establish conditions that must be considered in determining compliance with the qualifying conditions of the pre- and postclosure System Guidelines detailed in Section 6.2.2 and 6.3.2. The evaluations and findings are summarized in Table 6-7 in Section 6.2.1.8.5.

6.2.1.1 Site Ownership and Control (Postclosure), Guideline 10 CFR 960.4-2-8-2

The NRC requires the DOE to obtain ownership and control of land and minerals within the controlled area of the repository, or, the permanent withdrawal and reservation of such land for its use (10 CFR 60.121). Such rights are required largely to help ensure continued functioning of the repository far into the future without adverse human interference. Additional appropriate controls must be established beyond the controlled area as necessary to prevent adverse human actions that could significantly reduce the repository's ability to achieve isolation (10 CFR 60.121).

This guideline includes a qualifying condition, one favorable condition, and one potentially adverse condition for analysis. It does not have a disqualifying condition.

6.2.1.1.1 Statement of 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.

Evaluation Process. The evaluation process involves the identification of the land requirements for the repository, determination of current land ownership, and a judgment as to whether the guideline is or may be satisfied. A summary of the evaluation is presented in Table 6-7 in Section 6.2.1.8.5.

Relevant Data. The Richton Dome site is privately owned land; no DOE-owned lands are located in the vicinity of the proposed repository site (see Figure 3-38 and related discussion in Section 3.4.1; see also Section 4.1.3.3). As described in Section 5.1, a repository site will consist of (1) the geologic repository underground operations area of approximately 809 hectares (2,000 acres), (2) a fenced restricted area of about 165 hectares (407 acres) for support buildings and repository surface facilities, and (3) a controlled area extending outward from the edge of the underground facility. The total site area would be a maximum 2,222 hectares (5,489 acres) (see Section 5.1, Table 5-1).

Under EPA regulation 40 CFR 191.12, this controlled area could extend as far as 5 kilometers (3.1 miles) in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system, potentially encompassing thousands of acres. However, the controlled area need not be this large if EPA standards for radioactive releases to the accessible environment can be met in a shorter distance (40 CFR Part 191). The size of the controlled area at a given site will depend on the rate of ground-water flow and other site characteristics. It will be established on a site-specific basis after completion of site characterization studies, to ensure that releases to the accessible environment will not exceed those permitted by the EPA. Analysis of possible release mechanisms in Sections 6.3 and 6.4 indicates that the salt dome itself will provide adequate containment of the waste for time periods far in excess of requirements.

Assumptions and Data Uncertainty. The number of acres that comprise the controlled area is a conservative estimate based on available data at this time (see Chen and Raines, 1985). The margin of the salt dome at -1,829 meters (-2,000 feet) mean sea level (MSL) defines the amount of required controlled area based on an evaluation of expected conditions. This area of 2,222 hectares (5,489 acres) is considered adequate for this purpose; however, this estimate may be modified as a result of site characterization. As a separate consideration, the DOE does not anticipate that any additional control outside the controlled area will be required to prevent adverse human action (10 CFR 60.121[b]). The DOE controlled-area estimate is conservative and already includes a buffer area beyond that otherwise required on performance assessment grounds, to account for potential human intrusion (Chen and Raines, 1985).

The DOE has the authority to negotiate for lease or purchase of privately owned lands, or condemn if negotiations are unsuccessful. The Federal government has the right of eminent domain as an incident of sovereignty (U.S. v. Jones, 109 U.S. 513 [1883]). Both the Atomic Energy Act of 1954 (42 USC Section 2201 [g]) and the Department of Energy Act (42 USC Section 7257) confer express property acquisition and condemnation authority upon the DOE.

Analysis. The analysis considers ownership needs, the identification of current ownership of the proposed repository site, and a determination of the DOE's ability to satisfy the requirements for ownership and control.

6.2.1.1.2 Analysis of Favorable Condition.

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

Evaluation. The DOE does not own and control either land or surface or subsurface rights at Richton Dome. The DOE will have to acquire the necessary land and rights.

The evidence indicates that the favorable condition is not present.

6.2.1.1.3 Analysis of 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.

Evaluation. The Richton Dome site is located on privately owned land for which the DOE can negotiate voluntary purchase-sell agreements. If negotiations of such agreements are unsuccessful, the DOE can obtain the necessary ownership rights by condemnation. Required interest in land will have been acquired by the DOE in the preclosure time period, if the site is selected for a repository, and there will be no postclosure land-ownership conflicts.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.1.4 Analysis of Disqualifying Condition. The guideline concerning site ownership and control does not contain a disqualifying condition.

6.2.1.1.5 Conclusion for Qualifying Condition. The favorable condition is not met since the DOE does not own the land. However, private land ownership does not preclude acquisition of necessary land by the DOE. The DOE can obtain ownership by condemnation if negotiations are unsuccessful. The DOE will be able to acquire all land required for repository construction, operation, and closure to ensure that any site activities will not lead to a projection of radionuclide releases to an unrestricted area in excess of those in Section 960.4-1.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.2 Population Density and Distribution, Guideline 10 CFR 960.5-2-1

The objective of the population density and distribution guideline is to ensure the selection of a repository site that will minimize risk to the public and permit compliance with the EPA and NRC regulations. The EPA standard (40 CFR Part 191) limits exposures to members of the public and further requires they be reduced below the limits to the extent reasonably achievable. The EPA 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. (Doses from natural background radiation vary between 70 and 200 millirems per year at different locations in the United States.)

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 Statement of 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).

Evaluation Process. A conservative approach was taken for assessing compliance with this guideline by showing that an individual at the site boundary, exposed continuously to normal operational and accidental releases of radioactivity, will not receive a dose that exceeds a small fraction of the limits. Both construction and operation of the facility are considered. This requires knowledge of the characteristics of the release rate of each radionuclide and the release height, and atmospheric transport-related parameters, receptor location and number, dose equivalent, properties of the radionuclides released, a dose assessment, and a comparison to the EPA dose limits (40 CFR Part 191).

The guideline requires consideration of (1) the population density in the general region of the site, (2) the remoteness of the site from highly populated areas (population 2,500 or more), (3) the 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-kilometer by 1.6-kilometer (1-mile by 1-mile) area, and (5) the ability to develop an Emergency Preparedness Plan.

Relevant Data. Section 6.4.1 contains a discussion of characteristics of the release rate of each radionuclide and the release height, atmospheric transport-related parameters, dosimetric properties of the radionuclides released, and dose assessment results. The primary sources of data for this analysis are found in Sections 3.4.1 (Land Use), 3.4.3 (Meteorology), 3.6.1 (Population Density and Distribution), 5.1 (The Repository), and 6.4.1 (Preclosure Radiological Assessment).

Assumptions and Data Uncertainty. Used in this analysis are demographic data for the Richton Dome region collected during the 1980 census and compiled in the Socioeconomic Data Base Report for Mississippi (BNI, 1984, ONWI-499). Population distributions utilized in the analyses for this guideline are broken down into zones that conform to meteorological conditions to a distance of 80 kilometers (50 miles) from the site (see Section 3.6.1.1). Aerial photographs at a scale of 2.5 centimeters = 152 meters (1 inch = 500 feet) are used to provide estimates of proximity of residents to the surface facility.

Meteorological data from the Richton Dome site are not available. However, the proximity of the Jackson weather station and the lack of severe intervening topography or major bodies of water make it likely that the Jackson data are reasonably representative of Richton Dome weather.

The facility design must be considered preliminary and subject to continuing change. This design is believed to be reasonably representative of the repository operational systems likely to be included in future designs. For this evaluation, the site boundary is considered to be at the outer edge of the restricted area (surface facility). Analyses of releases and exposures during closure have not been made; however, these are expected to be less than operational values.

Analysis. Radiological analyses are detailed in Section 6.4.1. In the first evaluation, releases of radionuclides at the point of release are compared to the applicable 10 CFR Part 20 (NRC, 1983) requirements for maximum permissible concentrations in unrestricted areas. In the second evaluation, an analysis is made of the annual dose to a hypothetical individual who is presumed to be continually at the point of maximum exposure in the unrestricted area. This exposure is compared to regulatory limits.

6.2.1.2.2 Analysis of Favorable Conditions.

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

Evaluation. The average population density in the region of the site is 40 persons per 2.6 square kilometers (1 square mile), which is lower than the national average of 76 for the continental United States. Richton Dome is located in Perry County, which has a population density of 15.2 persons per 2.6 square kilometers (1 square mile). The general region of the site is defined as being within an 80-kilometer (50-mile) radius of the site. The population distribution within this region is discussed in Section 3.6.1.1.

The evidence indicates that the favorable condition is present.

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

Evaluation. Any evaluation of this favorable condition requires a precise definition of remoteness, which is not provided in the guidelines. Therefore, for the purposes of this evaluation, remoteness has been equated to a distance of 8 kilometers (5 miles) beyond the anticipated boundary of the controlled area.

The 8-kilometer (5-mile) criterion is based on analogy with two nuclear power reactor precedents. First, for U.S. nuclear power plants the Low Population Zones (LPZ) vary from 0.97 to 9.7 kilometers (0.6 to 6 miles) as calculated on the basis of "Reactor Site Criteria" 10 CFR 100.11 (Pearlman and Waite, 1984, p. 40). Also, evacuation zones in Federal Emergency Management Agency (FEMA) regulations are defined by radii of 3.2 and 8 kilometers (2 and 5 miles) (Pearlman and Waite, 1984, p. 41).

The preclosure emissions from the repository will originate within the restricted area. A conservative approach of originating the 8-kilometer (5-mile) measurement on the boundary of the controlled area was adopted. The nearest highly populated area is Petal/Hattiesburg (population 49,300), located 25 kilometers (16 miles) in air distance away from the boundary of the controlled area.

The evidence indicates that the favorable condition is present.

6.2.1.2.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. The residential population within the dome area is approximately 140, based on an estimate of 50 homes and an average household size of 2.8 (BNI, 1984, ONWI-499). No residences exist within the proposed restricted area boundaries. Seasonal population fluctuations are expected to be minimal. The daytime population may vary by as much as 100 due to the school located near the southeast portion of the dome area. Combined residential and daytime population increases represent an estimated population density in the projected site boundary of 28 persons per 2.6 square kilometers (1 square mile), well below the national average of 76 persons per 2.6 square kilometers (1 square mile) for the continental United States.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. The town of Richton, with a population of 1,205 within an approximate 2.6-square-kilometer (1-square-mile) area, is near the controlled area boundary. The town is, however, 3.2 kilometers (2.0 miles) from the boundary of the proposed restricted area (surface facility).

The evidence indicates that the potentially adverse condition is present.

6.2.1.2.4 Analysis of Disqualifying Conditions.

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

Evaluation. As stated above in the discussion of favorable condition (1), the surface facilities (restricted area) are not located in a highly populated area.

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).

(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.

Evaluation. As stated in the discussion of adverse condition(s), the town of Richton is located 3.2 kilometers (2.0 miles) from the edge of the proposed surface facility.

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).

(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in the DOE Order 5500.3 (Reactor and Non-Reactor Nuclear Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations, DOE, 1981) and related guides or, when issued by the NRC, in 10 CFR Part 60, Subpart I, "Emergency Planning Criteria."

Evaluation. Since the issuance of the DOE Order 5500.3 in August 1981, the DOE has developed emergency preparedness programs for its facilities throughout the United States. Emergency preparedness programs have been developed for Oak Ridge, Tennessee (DOE, 1977) and Savannah River, Georgia (DOE, 1983a). In both instances, the sites are in rural, humid areas similar to the Richton Dome site.

The recent experiences of the DOE in preparing emergency preparedness programs in response to the DOE Order 5500.3, and specifically the successful experiences at Oak Ridge and Savannah River, provide an expectation of confidence that the DOE will be able to develop an emergency preparedness program at the Richton Dome site. Further, in its assessment of the requirements of this Order, the DOE could find no site-specific conditions that would prevent the preparation of an emergency preparedness program for the site. The "Emergency Planning Criteria," 10 CFR Part 60, Subpart I, have not yet been issued by the NRC.

The evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.2.5 Conclusion for Qualifying Condition. The Richton Dome site is not in a highly populated area. Current designs place the repository restricted area (surface facility) 3.2 kilometers (2.0 miles) from the town of Richton.

The major concern of this guideline is the protection of the public from the radiation doses exceeding the limits allowable under Section 960.5-1(a)(1). As shown in Section 6.4.1, the maximum exposed individual is expected to receive an annual dose of less than 0.07 millirem per year from all pathways (inhalation, submersion, and ingestion). This exposure is well below the regulatory limit of 25 millirems per year. Atmospheric dispersion can be expected to further reduce concentrations before released radionuclides are transported to the environment outside the restricted area. The annual radionuclide dose to a maximum exposed individual at the boundary of the restricted area is substantially below the allowable limit specified in 10 CFR 960.5-1(a)(1). Experience shows that the DOE will be able to develop an appropriate Emergency Preparedness Program.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.3 Site Ownership and Control (Preclosure), Guideline 10 CFR 960.5-2-2

Although the preclosure and the postclosure guidelines on site ownership and control are stated in similar terms (see Section 960.4-2-8-2), they are related to different System Guidelines (i.e., the preclosure and the postclosure System Guidelines). The necessary land areas and controls required may differ slightly, as discussed in the preamble for Section 960.4-2-8-2.

This guideline includes a qualifying condition, one favorable condition, and one potentially adverse condition for analysis. It does not have a disqualifying condition.

6.2.1.3.1 Statement of 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).

Evaluation Process. The evaluation process involves the identification of land requirements for the site characterization and the repository, identification of current land ownership, and a judgment as to whether or not the guideline is or may be satisfied.

Relevant Data. The Richton Dome site is all privately owned land; no DOE-owned lands are located near the candidate repository site. The baseline data are presented in Section 3.4.1. Figure 3-2 depicts the proposed restricted area and the controlled area at the Richton Dome Site. Section 4.1 describes proposed site characterization activities, associated land requirements, and land acquisition mechanisms. Section 5.1 describes the proposed repository facility and operations, including land requirements and acquisition.

Assumptions and Data Uncertainty. The number of acres that comprise the controlled area is a conservative estimate based on data available at this time. This estimate may be modified as a result of site characterization.

Analysis. Analysis performed in Section 6.4.1 provides the calculations of radionuclide release to the unrestricted area. This analysis indicates that the proposed controlled area and restricted area are of sufficient extent to assure compliance with the requirements specified in 10 CFR 960.5-1(a)(1).

6.2.1.3.2 Analysis of Favorable Condition.

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

Evaluation. The DOE does not presently own and control land and all surface and subsurface mineral and water rights. The DOE will have to acquire the necessary rights.

The evidence indicates that the favorable condition is not present.

6.2.1.3.3 Analysis of 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.

Evaluation. The Richton Dome site is located on privately owned land for which the DOE can negotiate voluntary purchase agreements. If negotiations of such agreements are unsuccessful, the DOE may obtain the necessary rights by condemnation.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.3.4 Analysis of Disqualifying Condition. The site ownership and control guideline does not have a disqualifying condition.

6.2.1.3.5 Conclusion for Qualifying Condition. The site is located on privately owned land, title to which can be obtained by negotiation or by condemnation, if necessary to ensure that any site activities will not lead to a projection of radionuclide releases to an unrestricted area greater than those in Section 960.5-1(a)(1).

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.4 Meteorology, Guideline 10 CFR 960.5-2-3

The principal objective of the preclosure guideline on meteorology is to ensure that the weather conditions at the site are favorable for the atmospheric dispersion of any radioactive emissions and to ensure compliance with the System Guideline for preclosure radiological safety. Also of concern is the potential for extreme weather phenomena that could affect the operation and safety of the repository.

This guideline includes a qualifying condition, one favorable condition, and two potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.2.1.4.1 Statement of 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 requirement specified in Section 960.5-1(a)(1).

Evaluation Process. The approach for assessing compliance with this guideline is to show that the prevailing meteorological conditions at the site would act to effectively disperse any radioactive emissions from the site such that the whole body doses received by a receptor do not exceed the allowable limits. This evaluation process requires an understanding of the characteristics of the release rate and release height of each radionuclide; dispersion data; the receptor location and number; the dose equivalent properties of the radionuclides released; dose assessments; a comparison with NRC release limits (10 CFR Part 20); and a comparison with EPA whole body dose limits (40 CFR Part 191). The approach also assesses the potential for radiological emissions to be caused by a meteorological event. The evaluation process requires an assessment of the frequency and intensity of extreme weather events, including tornadoes, hurricanes, rainstorms, flooding, snowstorms, maximum snowload, and high wind speed. Both repository operation and closure are considered under normal operations (Sections 6.4.1.2 and 6.4.1.3) as well as accident conditions (Section 6.4.1.4).

Relevant Data. The primary sources of data for this analysis are as follows:

- Facility Design. The design used in this analysis is presented in Section 5.1.
- Meteorological Conditions and Assessment. Meteorological data from Jackson, Mississippi, are used and are summarized in Section 3.4.3.
- Demography. Population distribution and density are presented in Section 3.6.1.
- Preclosure Radiological Assessment. Postulated radionuclide release scenarios and an evaluation of release transport and diffusion factors are presented in Section 6.4.1.

Assumptions and Data Uncertainty. The repository design used for this evaluation is not final; however, expected releases from the facility can be reasonably estimated based on experience with other radioactive materials handling operations. The region for which the population-exposure rate is calculated includes Mississippi counties within an 80-kilometer (50-mile) radius of the site.

Long-term climatological and meteorological data at the Richton Dome site are not available. However, the proximity of the Jackson weather station and the similarity of the terrain between this station and the site provide a reasonable base of technical information for estimating meteorologic conditions likely to occur at the site.

The data base on extreme weather phenomena that might be experienced in the area is typical of data that have been used to establish design parameters for other licensed nuclear facilities. Other nuclear facilities (Grand Gulf and Waterford, for example) have been designed to withstand severe weather phenomena. Guidance on appropriate parameters to be considered is provided in Regulatory Guide 1.70 (NRC, 1978a).

The repository closure phase is not specifically discussed here. However, documentation of previous nuclear reactor facility decommissioning studies indicates that, under any conditions, radioactive releases have been controlled to levels below those during the operations phase (see Section 6.4.1.1).

Analysis. Two types of evaluations are used to show compliance with 10 CFR Part 20, and 40 CFR Part 191, Subpart A, the regulations specified in guideline Section 960.5-1(a)(1). In the first evaluation, emissions of radionuclides at the point of release are compared to 10 CFR Part 20 requirements for maximum permissible concentrations in unrestricted areas. In the second evaluation, an analysis is made of the annual dose received by a hypothetical individual presumed to be continually at the point of maximum exposure in the unrestricted area. Both analyses are detailed in Section 6.4.1.

Analysis of releases and exposures during closure have not been made, but are expected to be lower than operational values.

6.2.1.4.2 Analysis of 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.

Evaluation. The analysis of atmospheric stability data and wind speeds indicates that prevailing meteorological conditions are expected to provide fair to good atmospheric dispersion in the area of the Richton Dome site. The prevailing mixing levels and relatively infrequent occurrence of stagnation episodes favor good dispersion. In addition, local topographic influences on local dispersion processes should not be significant because terrain is relatively flat to rolling (Section 3.4.3.1).

The evidence indicates that the favorable condition is present.

6.2.1.4.3 Analysis of Potentially Adverse Conditions.

(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 average for the region.

Evaluation. The average population density in the dome region (80-kilometer [50-mile] radius) is 40 persons per 2.6 square kilometers (1 square mile) (Section 6.2.1.2.3). The prevailing wind (based on wind rose information on 22½ degree sectors) in the area as measured in Jackson is from the south-southeast (Section 3.4.3.4). Based upon a 22.5 degree downwind sector and U.S. Geologic Survey 1:250,000 topographic maps, the nearest localities downwind of the site are Laurel, population 21,897 at 40 kilometers (24 miles), and Bay Springs, population 18,084 at 78 kilometers (49 miles). Since the intent of this guideline is to address the prevailing wind, the 50 percent wind direction sector used in the draft environmental assessment was abandoned in favor of this smaller section dimension. The presence of these localities downwind of the facility is sufficient to find the adverse condition present. Preliminary radiological analyses of emissions are presented in Section 6.4.1.

The evidence indicates that the potentially adverse condition is present.

(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.

Evaluation. The frequencies of extreme weather phenomena in the site area are discussed in Section 3.4.3.3. From 1886 to 1984, 45 tropical storms and hurricanes entered Mississippi, virtually all of which would have affected weather conditions in the site area. Some nearby flooding is possible due to excessive rainfall associated with these storms. A total of 49 tornadoes occurred between 1955 and 1967 over a 20,953-square-kilometer (8,090-square-mile) area, which includes the site. The recurrence interval for tornadoes at the site is approximately 932 years. On the average, the site area can expect thunderstorms about 70 days per year, hail 2 days per year, and heavy fog 30 days per year. Snowfall (1.0 inch or more) and freezing rain occur infrequently, averaging less than 1 day per year. The repository will be designed to allow safe operation during these periods of extreme weather; however, some material shipments and work-force commutes could be disrupted.

The evidence indicates that the potentially adverse condition is present.

6.2.1.4.4 Analysis of Disqualifying Condition. The meteorological guideline does not have a disqualifying condition.

6.2.1.4.5 Conclusion for Qualifying Condition. The requirements of the qualifying condition of this guideline are that the radionuclide releases to an unrestricted area are not likely to be greater than those allowable under the requirements of Section 960.5-1(a)(1), or, specifically, that releases and dispersion meet the requirements of

- 10 CFR Part 60
- 40 CFR Part 191
- 10 CFR Part 20.

For the first evaluation, Section 6.4.1 shows that repository operation and closure will result in radionuclide concentrations of less than 5.0 percent of 10 CFR Part 20 limits for releases to the unrestricted environment. Atmospheric dispersion can be expected to further reduce concentrations.

For the second evaluation, as shown in Section 6.4.1, the maximum exposed individual is expected to receive an annual whole body dose of less than 0.66 millirem per year from all pathways (inhalation, submersion, and ingestion). This exposure is well below the regulatory limit of 25 millirems per year.

The meteorology at the site helps to satisfy the preclosure radiological safety System Guideline in that any releases from the repository can generally be expected to disperse to safe levels before leaving the restricted area. Thus, population concentrations downwind from the facility will be adequately protected.

The potentially adverse extreme weather conditions found at the site will be accommodated in repository design. The most significant impacts are expected to be delays in transportation of workers and material to and from the repository.

The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.5 Offsite Installations and Operations, Guideline 10 CFR 960.5-2-4

The preclosure Technical Guideline on offsite installations and operations has two objectives: (1) to ensure that the impacts of any nearby industrial, transportation, military, and atomic energy defense installations and operations on repository siting, construction, operation, closure, and decommissioning are adequately considered; and (2) to ensure that any radionuclide emissions from such installations, when combined with preclosure emissions from the repository, would not lead to total radiological exposures in any unrestricted area greater than those allowed by the requirements specified in the pertinent System Guideline.

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

6.2.1.5.1 Statement of Qualifying Condition.

> 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 Section 960.5-1(a)(1).

6.2.1.5.2 Evaluation Process. This section discusses the process used to determine whether the qualifying condition can be met by a repository at the Richton Dome site. The data, assumptions, and method of analysis used to derive the findings in subsequent sections are described below.

Offsite facilities or operations are considered hazardous if potential accidents at an offsite location might jeopardize the safety of the repository or its staff (NRC, 1978b, Regulatory Guide 1.91). Several examples of the hazards that might be produced by accidents at offsite installations or operations follow:

- Shock waves
- Missiles (ejecta from an explosion)

- Incendiary fragments
- Flammable vapor clouds
- Toxic chemical clouds.

Relevant Data. Data relevant to the evaluation of this guideline include (1) proximity of nearby hazardous facilities and operations and identification of the type of hazard they could pose to a repository and (2) proximity of or emission from other nuclear facilities or operations near the site.

Data are provided in Section 3.5 for any of the facilities or operations (and their associated hazards) listed below which exist within 8 kilometers (5 miles) of the potential repository operations area.

- Chemical plants (fire, explosion, and toxic hazards)
- Refineries (fire, explosion, and toxic hazards)
- Mining and quarrying operations (explosion)
- Oil/gas wells (explosion and fire)
- Gas/petroleum storage installations (fire, explosion, and toxic hazard)
- Military munitions storage areas (explosion)
- Military operations (explosion)
- Airports (aircraft crash and fire)
- Transportation and hazardous materials by the following modes:
  - waterway (explosion and toxic hazards)
  - railroad (explosion and toxic hazards)
  - highway (explosion and toxic hazards)
  - pipeline (explosion)
  - aircraft (crash and fire).

Existing nuclear facilities and operations within an 80-kilometer (50-mile) radius of the site are identified in the analysis of the favorable and adverse conditions. If the emissions are known, they are also provided.

Assumptions and Data Uncertainty. An underlying assumption of the evaluation is that the hazards identified by the NRC (1978b) in Regulatory Guide 1.91 for nuclear power plants are the same hazards that should be of concern for repositories. Further, the NRC and utility applicants have performed analyses that are used to establish the repository's degree of vulnerability to such hazards. The analysis assumes that repository safety-related facilities and operations will be designed and constructed to the same standards of safety as for nuclear power plants (for example, the waste handling building will be tornado-proof).

The term "nearby" for evaluation of hazardous installations under this guideline is defined in the NRC (1975) Regulatory Guide 4.7 (for located nuclear facilities) as being within an 8-kilometer (5-mile) radius of the site. When assessing the potential for cumulative radiological impacts of the repository combined with other nuclear facilities in the locality, an 80-kilometer (50-mile) radius from the repository was used (NRC, 1976).

Analysis. Analyses of explosive hazards, toxic hazards, airplane crashes, and radioactive releases were performed as described below. If one or more hazards were identified, a potentially adverse condition is present.

Explosive Hazards. The procedures adopted by the NRC (1978b) in Regulatory Guide 1.91 provide for the evaluation of safe standoff distances by comparison of explosive hazards to the equivalent hazard of TNT. For solid substances not intended for use as explosives, but subject to accidental detonation, the NRC states that it is conservative to assume that the solid material is equivalent to TNT on a mass basis (100 percent equivalency).

The NRC further states that the maximum probable explosive cargo for a highway truck is 22,600 kilograms (50,000 pounds), and for a railroad box car is 60,000 kilograms (132,000 pounds). Based upon these TNT equivalents, a safe standoff distance from a public highway on which TNT may be transported is 610 meters (2,000 feet), and from a railroad is

914 meters (3,000 feet). The overpressures at these distances would be below repository design levels.

A natural gas pipeline crosses the dome within about 1,800 meters (6,000 feet) of the proposed surface facilities (Section 3.5.5). This distance would be a safe standoff distance for 900,000 kilograms (2 million pounds) of TNT. For confined (and well mixed) gases, the NRC states that a prudent equivalency to TNT is 240 percent. However, accident release scenarios for a pipeline create unconfined gases. One scenario involves the rupture of a length (several hundred feet) of pipeline and explosion; the other is a puncture and explosion. Either way, the gas is unconfined and not well mixed. Under such circumstances, NRC found accidents show equivalency of 10 percent.

Assuming that this pipeline is a 40.6-centimeter (16-inch) pipeline under 3.5 million pascals (500 pounds per square inch), it would contain about 3 kilograms of natural gas per meter (2 pounds of natural gas per foot) of pipeline. For an accident damage to the repository, the gas contents of 3,000 kilometers (1,900 miles) of pipeline (at 10 percent equivalency) or 127 kilometers (79 miles) of pipeline (at 240 percent equivalency) would be required to explode at the closest point to the repository. The DOE believes that either case is beyond credibility.

Toxic Hazards. A determination was made as to whether any source of toxic hazards will be located within 8 kilometers (5 miles) of the repository site. If a source of toxic hazard exists such as a road or rail line on which toxic chemicals like chlorine are carried, a potentially adverse condition is present. Mississippi State Highways 15 and 42, potential sources of toxic hazard, are 5 kilometers (3 miles) and 3 kilometers (2 miles) from the site, respectively.

Airplane Crashes. Three general subdivisions of airspace are considered. In the first, uncontrolled airspace, air traffic is so infrequent that the NRC does not consider it a risk. In the second, the case at Richton Dome, the facility lies near controlled airways, and is subject to risk from in-flight crashes. A methodology established in the NRC's Standard Review Plan 3.5.1.6 (NRC, 1979, NUREG-0555) shows that the frequency of such events is a product of the in-flight crash rate for aircraft using the airways, the number of flights per year, the effective critical area of the unit (square miles), and the inverse of the width of the airway. Using TVA (Tennessee Valley Authority, 1976) data of 5×10^{-10} crashes per mile, 10,000 flights per year, an effective critical area (crash area) of 0.008 square kilometer (0.003 square mile), and an airway width of 14.8 kilometers (9.2 miles), the annual probability would be 1.6×10^{-9} per year, or approximately 1/100 of the NRC level for credible accidents. The third subdivision is takeoffs and landings, which require another methodology. Because the Richton Dome is not within a takeoff or landing path (NOAA, 1984), this subdivision is not discussed further.

Radioactive Releases. The nuclear facility or operation existing nearest the proposed repository operations area at Richton Dome is a power reactor at Port Gibson, Mississippi, approximately 210 kilometers (130 miles) away. If releases from such facilities or operations are regulated to 10 CFR Part 20 standards and are greater than 80 kilometers (50 miles) from the repository, no calculation of emissions was made because any contributing releases would be negligible-to-zero. The analysis in Section 6.4.1 indicates that doses from the repository operations would be orders of magnitude below natural background levels, and maximum individual doses from accidental releases would be 1/10,000 the dose that would be received by the same individual from natural background radiation at the same geographical location.

In the analysis of favorable and adverse conditions the dose from other facilities or operations within 80 kilometers (50 miles) was added to the dose received from a repository directly without taking credit for the dispersion that will occur beyond facility boundaries.

6.2.1.5.3 Analysis of Favorable Condition.

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

Evaluation. Because the nearest nuclear facility, a power reactor at Port Gibson, Mississippi, is greater than 80 kilometers (50 miles) away (approximately 210 kilometers [130 miles]), the contributing radioactive releases from this distant facility would be so small as to be negligible (ANS, 1983).

The evidence indicates that the favorable condition is present.

6.2.1.5.4 Analysis of Potentially Adverse Conditions.

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

Evaluation. Mississippi State Highway 42 crosses the dome from Hattiesburg in the west to Richton and passes about 3 kilometers (2 miles) from the surface facilities. Mississippi State Highway 15 passes through Richton, about 5 kilometers (3 miles) from the site (Section 3.5.1). A 40-centimeter (16-inch)-diameter underground pipeline, owned by United Gas, lies southwest of the dome, about 1.6 kilometers (1 mile) from the site. Based on the analysis above, this pipeline is not considered to be a hazard. The nearest railroad is located more than 19 kilometers (12 miles) from the site (Section 3.5.2). The railroad and pipeline should not pose a hazard based on the analysis in Section 6.2.1.5.2. The potential exists for transport of dangerous chemicals or explosives via highway corridors.

The Tiger oil and gas field, with four producing wells, is 3 kilometers (2 miles) north of Richton Dome. The Glazier oil field, with five producing wells, is 5 kilometers (3 miles) southeast of the dome. The potential for explosion and fire exists at such facilities; however, such an incident is unlikely to impact repository operations at the Richton Dome site.

The De Soto Military Operations Area airspace extends over the southern part of the dome and within the 8-kilometer (5-mile)-radius area. The airspace is restricted because of Camp Shelby's military operations. Future expansion of the restricted airspace or increased use could raise the level of risk to the facility from airplane crashes, in which case the DOE would reassess the hazards to the facility. The Richton Airport is located 4.8 kilometers (3 miles) south of the dome (Section 3.5.3).

The evaluation section demonstrates that the Richton Dome site is not within a takeoff and landing pattern, but is near controlled airways. The examination of airplane crash risks, using the NRC's methodology, shows the risk to the repository to be two orders of magnitude below the NRC's level for credible accidents. Therefore, there is no credible risk to the repository from aircraft operations.

Although no sources of toxic materials are known to exist within 8 kilometers (5 miles), there is the potential that toxic clouds would form and threaten the safety of the site should accidents occur on Mississippi State Highways 15 or 42.

The evidence indicates that the potentially adverse condition is present.

(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 (EPA, 1982a) or 40 CFR Part 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

Evaluation. There are no nuclear facilities within 80 kilometers (50 miles) of the site (Section 6.2.1.5.3). The cutoff distance used for this analysis is based upon NRC (1978a) Regulatory Guide 1.70.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.5.5 Analysis of 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.

Evaluation. No atomic energy defense activities are located in proximity to the site (ONWI, 1984).

The evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.5.6 Conclusion for Qualifying Condition. The major concern of this guideline is the presence of other facilities in the vicinity of the repository which would significantly interfere with repository construction, operation, or closure, or emit radionuclides which, when combined with emissions from the repository, could exceed permissible levels.

There is no nuclear facility within the 80-kilometer (50-mile) radius of the repository site, nor any other facility emitting radionuclides. Radionuclide emissions from the repository itself are expected to be well within permissible levels (Section 6.4.1). Based on present knowledge and assumptions, emissions from the repository, combined with those from other sources, would not exceed the levels of total radionuclide releases to unrestricted areas allowed by 10 CFR Part 20, 10 CFR Part 60, and 40 CFR Part 191.

A potentially adverse condition is present due to the presence of two highways in the locality of the repository site. This condition is not so adverse as to indicate that the qualifying condition could not be met, because the DOE can and will obtain relocation of the nearby access roads, if deemed necessary. Additionally, the hazards identified can be accommodated by designing (1) facilities which are adequately hardened against them and (2) operational safeguards that minimize any effects that may occur from explosions or fires. Accommodating such hazards is typical within the nuclear power plant industry (NRC, 1978a).

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.6 Environmental Quality, Guideline 10 CFR 960.5-2-5

The objective of the environmental quality guideline is to ensure that environmental impacts will be considered throughout all stages of the program and that adverse impacts will be mitigated to an acceptable degree. This guideline addresses these issues by identifying the ways in which potential sites will qualify and be disqualified based on environmental criteria, and by identifying specific favorable and potentially adverse conditions.

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

6.2.1.6.1 Statement of 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.

Evaluation. This section discusses the methods used to determine whether the qualifying condition can be met by a repository at the Richton Dome site. The data, assumptions and method of analysis used to reach the findings in subsequent sections are described below.

Relevant Data. Baseline environmental conditions are presented within Chapter 3, including air quality (Section 3.4.3.1), water quality (Section 3.3.1.2 and Section 3.3.2.3), water use (Section 3.3.3), land use (Section 3.4.1), biota (Section 3.4.2), nationally designated areas (Section 3.4.6), and State, Native-American and other significant areas (Section 3.4.6). Statutes and other regulatory requirements promulgated for protection of the environment are integral to evaluations of this guideline. Federal statutes, the State statutes for which a Federal statute mandates compliance, Executive Orders, and implementing regulations that are potentially applicable to the DOE's activities at the proposed repository site, are listed in Table 6-2. The table also presents the purpose and intent of each authority, the requirements for compliance, the actions taken or planned by the DOE to demonstrate compliance, and the DOE's projected ability to comply with the regulatory requirements.

Table 6-3 lists non-Federally-derived State and local environmental requirements. The DOE intends to comply with all State and local environmental requirements not inconsistent with our responsibilities under the NWPA. The DOE intends to consult with State and local officials concerning sites that are recommended, to determine the scope of the above-noted requirements and to identify other regulations as appropriate.

The physical and environmental setting of the site is described in Section 3.4. Descriptions of the proposed activities associated with site characterization, repository construction, operation, closure, and decommissioning are presented in Sections 4.1 and 5.1. The assessment of the environmental impacts of the proposed activities associated with site characterization and with repository construction, operation, closure, and decommissioning is presented in Sections 4.2 and 5.2.

Table 6-4 summarizes the potential significant adverse environmental impacts from site characterization and repository construction, and planned control measures to be employed to mitigate the impacts. The projected effectiveness of the control measures and the acceptability of any residual impact are also described. Control measures presented are representative of the types that have been widely used for similar projects and have general acceptance. Other control measures may be identified or required depending on the results of ongoing analyses. Where this tabular information summarizes presentations in previous chapters, cross-references are provided.

Assumptions and Data Uncertainty. The environmental data used in these analyses are based on several site-specific, area, and regional studies. In some cases, application of the data base to this site involves assumptions about the similarity of the site to the surrounding region. These assumptions often involve projections about the outcome of environmental data-gathering based on the DOE's current understanding of area and regional information. Conservative assumptions of site conditions or project activities have been made where appropriate and are addressed in Chapters 4 and 5. Information used in the analysis regarding regulatory requirements is derived from legislative acts, executive orders, and attendant implementing regulations. The analysis is thus a projection of anticipated compliance with referenced environmental requirements.

Projected ability to comply with regulatory requirements assumes that compliance activities can be completed (1) within normal regulatory agency review time periods, and (2) without unusual information requirements by regulatory agencies. It is also dependent on the utilization of existing engineering technology and construction methods to achieve standards of environmental control which are implicit in the compliance projections.

Analysis. The evaluation of projected ability to meet statutory requirements is based on an assessment of the degree to which the existing data, coupled with estimates of data to be obtained during characterization and assumptions about the use of available engineering technology and construction methods, indicate an ability to comply with the substantive and procedural provisions of applicable statutes, orders and regulations. The DOE's judgment as to its probable ability to comply with the overall requirements is also included in the evaluation. Projected ability to comply is indicated (Table 6-2) when it is likely, based on the

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
National Environmental Policy Act of 1969, 42 USC Sections 4321-4361 (NEPA) (40 CFR Part 1500) (as directed in Nuclear Waste Policy Act of 1982 NWPA , 42 USC Sections 10101 et seq.)	To establish a national policy that will encourage productive and enjoyable harmony between people and their environment and to promote efforts to prevent or eliminate damage to the environment.	• Act requires Federal agencies to assess the environmental impacts of major Federal actions significantly affecting the quality of the human environment. • The NWPA establishes that site characterization recommendation and activities are preliminary actions that do not require an EIS. Statutory environmental assessments are required for site nomination. An EIS is required for repository site recommendation. The NWPA provides that certain standard EIS content requirements need not be included.	This document is the Statutory EA under NWPA. DOE plans to prepare an EIS in accordance with NEPA as specified in NWPA.	DOE projects an ability to comply because it will prepare the required NEPA EIS.
Land Use				
Coastal Barrier Resources Act, 16 USC Sections 3501-3510	Act prohibits new Federal expenditures for construction of projects within the Coastal Barrier Resources System (CBRS), which consists of undeveloped coastal land along the Atlantic and Gulf Coasts and adjacent wetlands and inlets.	• DOE must determine if repository site or related activities are within the CBRS. If so, site and/or activities must be abandoned.	The requirements of this statute have been analyzed against proposed project activities. No activity related to a repository, including salt disposal, is proposed in areas covered by the Act (Fish and Wildlife Service, 1982).	Act is not applicable because no activities are proposed within coastal barriers (Section 4.1, 4.2, and 5.1).
Coastal Zone Management Resources Act, 16 USC Sections 1451-1465 (15 CFR Part 930)	Act ensures that any Federal project in the coastal zone of a State, or directly affecting the coastal zone, is consistent with approved State management programs.	• DOE must determine if project activities are in, or could affect, the coastal zone of a State. • If DOE determines that a coastal zone is affected, DOE must determine if the State involved has a Coastal Zone Management Program (CZMP) approved by the Secretary of Commerce. • DOE must review the State CZMP and consult with the State agency responsible for the CZMP, and perform a consistency determination.	• The requirements of this statute have been analyzed against proposed project activities. No activity related to the repository will affect areas covered by the Act. • Salt disposal sites may be selected in the future that could affect the coastal zone. If this were to occur, DOE would consult with the State and ensure consistency with Mississippi's approved CZMP.	DOE projects an ability to comply. Coastal zones would be affected only if certain salt disposal sites are selected. Should this occur, DOE will consult with the State and ensure consistency with the Mississippi CZMP.

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Coastal Zone Management Act of 1972 (Continued)		• DOE must obtain concurrence from the State with DOE's consistency determination for project to proceed. • DOE must initiate activities to determine if offshore disposal would be consistent with the approved State CZMP.		
Marine Protection, Research and Sanctuaries Act of 1972, 33 USC Sections 1401-1444 (40 CFR Parts 220-228)	Action and regulations regulate the dumping into ocean waters of all types of materials.	If DOE decides to dispose of salt in ocean water, a permit is required.	DOE has not selected ocean disposal as the reference option. If DOE decides to dispose of salt in ocean water, it will obtain a permit and proceed in a manner that meets the requirements of the Act.	DOE projects an ability to comply because if ocean disposal is chosen as the method of salt disposal, DOE will select an option that meets the requirements of the Act (Section 4.3.4.2).
Materials Act of 1947, 30 USC Sections 601-604 (43 CFR Part 3620)	Act was intended to remove common types of sand, gravel, and stone from coverage of mining laws.	A free use permit is required from Bureau of Land Management (BLM) if DOE plans to take sand, gravel, stone, or other common materials from BLM land.	DOE has determined that no BLM land is present in the project area (Section 3.4.1.2).	Act is not applicable because no BLM land is present in the project area.
Wild and Scenic Rivers Act, 16 USC Sections 1271-1287	Act prohibits construction on or directly affecting any river that is designated a component of the National Wild and Scenic River (NWSR) system, or on any river designated for addition to the system, that would adversely affect the values of the NWSR system.	• DOE must determine if any rivers in the vicinity of the project area are designated as a component of the NWSR system or a potential addition to the system. • If DOE finds a NWSR in the vicinity, it must prepare an impact evaluation. • If impacts are direct and adverse, DOE must advise the Secretary of the Interior and Congress.	Consultation with Department of the Interior (DOI) and U.S. Department of Agriculture (USDA) has determined that the Escatawpa River (located 45 miles to east) and Black Creek (located 25 miles to south) are potential additions to the NWSR system (Hess, 1985; Keene, 1984). Review of maps and proposed project activity determined that the Richton site and related repository support facility would not be in areas having drainage connection with either river (USGS, 1982; Section 3.4.1). There are no other units of NWSR in State of Mississippi (Hess, 1985).	DOE projects an ability to comply because no units of NWSR system have any drainage connection with the project area. Two potential additions to the NWSR system exist in the site vicinity; however, because of the lack of drainage connection, project activities at the site could not affect either river.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Wilderness Act, 16 USC Sections 1131-1136 (Federal Land Policy and Management Act, 43 USC Section 1782) (36 CFR 261.16 and 293.15; 43 CFR Parts 19, 3802, 8560; 50 CFR Part 35)	Act establishes a National Wilderness Preservation System for public recreational, scenic, scientific, educational, conservation, and historical use.	• Roads, structures, installations, etc., are prohibited in designated wilderness areas or wilderness study areas (WSAs). • DOE must avoid siting repository and support facilities within wilderness areas, as well as within WSAs until Congress has made a final determination whether to include them permanently as wilderness areas.	No designated or proposed wilderness areas or WSAs occur in the project area. However, two U.S. Forest Service designated wilderness areas, Leaf Wilderness area and Black Creek Wilderness area, occur approximately 25 miles south of the candidate site in De Soto National Forest (Braddock, 1985) (Section 3.4.1).	Statute is not applicable at this site because no wilderness areas or wilderness study areas occur at site or in vicinity.
Objects Affecting Navigable Airspace, 49 USC Section 1501 (14 CFR Part 77)	Regulations prevent construction of structures that would be a hazard to air navigation, and regulate other structures that could affect air navigation.	• DOE must notify the Federal Aviation Administration (FAA), using FAA Form 7460-1, of plans to construct any structure 200 ft, or greater, in height; plans to construct structure within a 100 to 1 slope at 20,000-ft distance (50 to 1 slope at 10,000-ft distance) of runway of public or military airport; and plans to construct structure within an instrument approach area. • DOE must comply with FAA's response to notification, which may include lighting and marking structure according to FAA specifications.	• DOE has determined that FAA notification will be necessary because repository service shaft headframe will exceed 200 ft in height (Section 5.1.1.3). No structure will be within 20,000 ft of a public or military runway, or within an instrument approach area (Sections 3.4.1; 3.5.3). • DOE will submit FAA Form 7460-1 notifying FAA of plans to construct 265-ft service shaft headframe and comply with any FAA instructions or requests for additional information or submittals.	DOE projects an ability to comply because submitting FAA forms and following FAA specifications or design modifications will satisfy requirements.
Federal Land Policy and Management Act of 1976, 43 USC Sections 1701-1784 (36 CFR Part 251; 43 CFR Parts 2300 and 2800)	Act and regulations authorize and establish procedures for Federal Departments and Agencies to use, occupy and develop public lands administered by the DOI through the BLM and Forest Service lands administered by the USDA. These mechanisms are rights-of-way withdrawals, and cooperative agreements.	• If site characterization occurs on DOI/BLM-managed lands, the DOE Secretary may negotiate and execute a cooperative agreement with the Department of the Interior and apply for required rights-of-way. The DOE must follow withdrawal procedures to protect the land. These procedures include: pre-application consultation with	• DOE has determined that no BLM or Forest Service land occurs at repository site. Land at the site is currently privately owned (Simpson, 1985) (Section 3.4.1). However, access routes will cross Forest Service land. • DOE will consult with Forest Service to obtain land for access right-of-way.	DOE projects an ability to comply because it will comply with procedural requirements of the Act and accomplish implementations of the Act in consultation with the Forest Service (USFS).

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Federal Land Policy and Management Act (Continued)		the BLM, submission of application, and preparation of resource management plan and implementation plan. The Secretary of Interior can authorize withdrawals up to 20 years. Withdrawals of 5,000 or more acres are subject to congressional review. In conducting the withdrawal activities, the DOE must comply with its internal procedural requirements set forth in DOE Real Estate (Real Property) Management Order (DOE 4300.1A). • If Forest Service land is involved, rights-of-way may be required. • If the repository were to be on DOI/BLM-managed lands, an Act of Congress will be required for permanent withdrawal or transfer, and FLPMA will not be applicable.		
Taylor Grazing Act, 43 USC Sections 315-316o (43 CFR Part 4100)	Act creates, protects and regulates Federal grazing districts to provide for the orderly use and development of rangeland.	If project area is located on a BLM-designated grazing allotment, DOE must apply for a right-of-way or withdrawal of grazing allotment land from BLM.	DOE has determined that project area is not located on public lands administered by DOI/BLM. There are no grazing leases in the project area (Simpson, 1985).	Act is not applicable at this site because no BLM-designated grazing allotment occurs in the project area.
National Trails System Act, 16 USC Sections 1241-1251	Act establishes and protects National Recreation, National Scenic, and National Historic Trails.	If a National Trail is located within the project area, DOE must determine if the project would be incompatible with the purposes of the Trail. Relocation of a Trail may be possible if repository characterization, construction, or operation is found to be incompatible with the purposes of the Trail; substantial relocation requires an Act of Congress.	Consultation with the DOI and USDA and review of published lists of National Trails have determined that no National Trails exist in the project area (Hess, 1985; Keene, 1984; NPS, 1984; NPS, 1983).	Act is not applicable at this site because no National Trails exist in the vicinity of the project area.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
National Forest Organic Legislation, 16 USC Sections 471a et seq. Multiple-Use Sustained-Yield Act of 1960, 16 USC Sections 528-531; Forest and Rangeland Renewable Resources Planning and Research Act, which includes the National Forest Management plans, and Renewable Resources Extension Program Plans, 16 USC Sections 1600-1676 (36 CFR Part 261)	Acts protect and improve National Forests, which are established for outdoor recreation, range, timber, watershed, and fish and wildlife purposes.	• DOE must obtain Congressional approval for withdrawal or transfer of National Forest land for DOE use as repository site. • Access roads on National Forest land must be built in accordance with requirements defined by Department of Agriculture. Permanent roads must be approved as part of National Forest Transportation System. A special use permit may be required for site characterization activities.	• DOE has determined that no National Forest land occurs on the candidate repository site (Gandy, 1985); National Forest land occurs approximately 3 miles north and 13 miles south of the candidate repository site and support facilities (USGS, 1982). Access corridors will cross Forest Service land (Section 3.4.1). • DOE has entered into a Memorandum of Understanding with USFWS to conduct certain preliminary geologic studies in the De Soto National Forest. • DOE will consult with USFS regarding easement for road right-of-way on Forest Serice land. (See Federal Land Policy and Management Act.)	DOE projects an ability to comply with the requirements because DOE will conduct future activities in De Soto National Forest in consultation with USFS in a manner consistent with statutory requirements.
Organic Act of the National Park Service, 16 USC Section 1; National Park System Mining Regulation Act, 16 USC Sections 1901-1912 (36 CFR Part 9)	Act 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 not locate the restricted area or repository support facilities within a National Park.	DOE has determined that the candidate repository site and support facilities do not lie within a National Park and that no National Park is within the Project area (Section 3.4.1; NPS, 1983).	Act is not applicable because project areas do not lie within a National Park.
Farmland Protection Policy Act, 7 USC Sections 4201-4209 (7 CFR Part 658)	Act seeks to minimize the extent to which Federal programs contribute to the unnecessary and irreversible conversion of farmland to nonagricultural uses.	• DOE must complete first part of Soil Conservation Service (SCS) Form AD 1006, and submit to SCS. • If SCS determines that prime farmland exists on site, DOE must complete a site assessment using criteria set forth in 7 CFR Part 658 or State criteria where they exist. • If a final score exceeds threshold level, DOE must consider mitigating measures to protect the prime farmland, and assure, to extent practicable, project compatibility with State and local programs and policies.	• DOE completed first part of Form AD 1006 and submitted it to SCS in Mississippi. SCS has determined that the site contains prime farmland soils (Brooks, 1985a). DOE has completed site assessment and has found final score to be marginally above threshold level stipulated in Act. There are no State or local farmland protection programs or policies applicable to Richton site (Brooks, 1985b). • DOE will consider alternative/mitigating measures to protect farmland, as appropriate.	DOE projects an ability to comply because Form AD 1006 has been completed in compliance with Act and alternatives/mitigating measures will be considered. The act does not require DOE to exclude a site from consideration based on its provisions.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Floodplain/Wetlands Executive Orders, E.O. 11988 and E.O. 11990 (10 CFR Part 1022)	Executive Orders require Federal agencies to implement regulations that will protect wetlands and minimize adverse effects from development in floodplains. DOE implementing regulations are contained in 10 CFR Part 1022.	• DOE must determine if wetlands or floodplains occur in project area. • If floodplains or wetlands are found to occur, DOE must publish notice in Federal Register; notify Federal, State, and local agencies of proposed action; prepare an assessment of proposed action (floodplain/wetlands assessment), which includes alternative measures to minimize impacts if the project proceeds in the floodplains/wetlands; and publish a statement of findings. • DOE actions in floodplains must be designed to minimize harm to floodplain. • Construction in a floodplain must be in accordance with Federal Insurance Administration regulations. • DOE should avoid construction in a wetland unless there is no practical alternative. • Underground storage tanks are regulated by the US EPA under the 1984 Amendments.	• DOE has reviewed Flood Hazard Boundary Maps (as specified in 10 CFR Part 1022) and has determined that none of the repository site is within a 100-year floodplain (U.S. Department of Housing and Urban Development, 1978; USGS, 1982) (Section 3.3.1). Based on preliminary evaluation and review of USGS quadrangle map, wetlands have been identified at the site (Section 4.2.1.2). DOE has determined that certain activities in wetlands may be necessary. • A description of the potential impacts to floodplains/wetlands has been placed in Section 4.2.1.2. • Federal Register notice of the DOEs proposed floodplains/-wetlands assessment giving the opportunity for public comment will be published should the site be recommended for characterization. • The DOE will publish a statement of findings subsequent tothe public comment period. Section 4.2.1.2.4 provides a description of existing wetlands and floodplains, and proposed actions, an assessment of the impacts, and a discussion of alternatives and mitigative measures.	DOE projects the ability to comply with its requirements under 10 CFR Part 1022 because the DOE has re-evaluated the practicability of the proposed floodplains/wetlands actions, taking into account public comments received, and will continue to evaluate practicable alternatives with representatives of applicable agencies. The DOE has taken into account mitigating measures and has designed the proposed floodplain/wetland actions to minimize potential harm to or within the floodplain/wetlands.
U.S. Department of Transportation Acts, 49 USC Section 303 and 23 USC Section 138	Acts preserve the natural beauty of the countryside, public parks, 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 an historic site of significance if there is no	Although the Acts do not impose any requirements directly on DOE, DOE will consult with the Department of Transportation to determine the applicability of these Acts to plans for upgrading Federal roads or Federal-aid highways.	DOE projects an ability to comply because it will consult with the Department of Transportation and consider alternatives and mitigation.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
<u>Waste Disposal</u>				
Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 USC Sections 9601-9657	Act 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 EPA must be notified in the event of a reportable release of a designated hazardous material.	Small quantities of generated hazardous wastes will be temporarily stored in drums and then disposed of offsite at licensed facilities. The DOE will comply with all notification requirements.	DOE projects an ability to comply. DOE will comply with all notification requirements in the event of an accidental spill.
Hazardous Materials Transportation Act, 49 USC Sections 1801-1812 (49 CFR Parts 171-178)	Act gives additional regulatory and enforcement authorities to the Secretary of Transportation in order 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.	The DOE will comply with all applicable provisions of the Act for transportation of any hazardous waste during site characterization and repository operation and for transportation of high level nuclear waste during repository operation.	DOE projects an ability to comply because it will follow DOT regulations regarding the transportation of hazardous and radioactive materials.
Solid Waste Disposal Act, as amended by Resource Conservation and Recovery Act of 1976, and the Hazardous and Solid Waste Amendments of 1984, 42 USC Sections 6901-6987 (40 CFR Parts 124, 240-247, 260-264, 266, 270, 271, 280, E.O. 12088)	Act contains two major regulatory programs. The Hazardous Waste Program prescribes a system of manifest, reporting, standards and permits to achieve controls on hazardous materials from generation to final disposal. These requirements apply to generators and transporters of hazardous waste and owners and operators of hazardous waste storage, treatment and disposal facilities, as well as owners of underground storage of tanks. The reuse, reclamation and recycling of hazardous waste also is subject to this regulatory program. The second major program requires each state to prepare a Solid Waste Management Plan to prohibit new open dumps, and can require upgrading or closing of all existing open dumps. Federal guidelines for solid waste collection, transport, separation, recovery and disposal practices in systems have promulgated.	• DOE must comply with all Federal, State, interstate and local requirements relating to the disposal, management, reclamation, recycling, or reuse 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 EPA and DOT manifesting, record keeping, reporting, packaging, labeling and placarding regulations. • All shipments of hazardous waste are subject to a manifest tracking system. • Until a State program is approved, DOE must comply with both State and Federal requirements. • Facilities that treat, store, dispose, recycle, reclaim or reuse hazardous waste must obtain permits. New facilities cannot operate until a permit has been issued by EPA or authorized State agency.	Under provisions in RCRA, Mississippi was granted final authorization by the U.S. EPA to manage its own hazardous and solid waste program, not including the 1984 Amendments. Final authorization was granted on 27 June 1984 (49 FR 24377) (June 13, 1984). All activities associated with hazardous and solid waste management are handled by the Mississippi State Board of Health or the Mississippi Department of Natural Resources, Bureau of Pollution Control. The DOE will consult with the Mississippi State Board of Health and the Mississippi Department of Natural Resources, Bureau of Pollution Control, concerning compliance with hazardous and solid waste laws. (See Mississippi Solid Waste Disposal Act below.)	DOE projects an ability to comply with this Act based on (1) the type and quantity of waste expected to be generated as described in Section 4.1.2.6, and (2) DOE's plans to use licensed transporters and disposal facilities for any wastes that will be generated. See Mississippi Solid and Hazardous Waste Disposal Act below.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Solid Waste Disposal Act (Continued)		• Nonhazardous wastes are regulated under applicable State, local, and regional solid waste plans. • Underground storage tanks are regulated by the EPA under the 1984 Amendments.		
Solid Waste Disposal Act of Mississippi. Miss. Code Ann. Sections 17-17-1 to 17-17-47, and 49-17-28 and -29.	Act provides a statewide program for the regulation of the disposal of solid and hazardous wastes.	• All solid and hazardous waste disposal facilities must be permitted by the Mississippi State Board of Health or the Mississippi Department of Natural Resources, Bureau of Pollution Control. The requirements of these agencies parallel those noted above under the Solid Waste Disposal Act, as amended. • Generators of hazardous wastes are subject to the Federal manifest system.	• DOE has projected types of wastes expected to be generated by site characterization activities and repository construction and operation. These wastes are primarily nonhazardous and include sewage treatment sludges, combustible solids such as paper and cartons, excavated solids including drill cuttings and salts, and freshwater and brine drilling. • DOE has determined that licensed landfills and other disposal facilities for both hazardous and nonhazardous waste are available. • DOE plans to use available landfills for nonhazardous wastes from site characterization. DOE will make final decisions regarding disposal of excess salt from the repository later from a host of feasible alternatives (Section 5.1.3.4). Hazardous waste, if any, will be placed into a licensed facility, such as one existing at Emelle, Alabama. • 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 prepare appropriate manifest papers for any hazardous waste generated.	DOE projects an ability to comply with the Act based on: (1) the type and quantity of waste expected to be generated as described in Section 4.1.2, and (2) DOE's plan to use licensed transporters and disposal facilities for any wastes that will be generated.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Solid Waste Disposal Act of Mississippi (Continued)			• Anticipated hazardous wastes are oils and solvents from maintenance operations. These will be stored in drums prior to disposal, recovery, or processing.	
<u>Ecology and Wildlife Protection</u>				
Migratory Bird Treaty Act, as amended, 16 USC Sections 703-711 (50 CFR 10.13)	This Act prohibits killing, capturing, transporting, etc., of protected migratory birds, and their nests and eggs.	Project activities must avoid harm (including indirect effects) to migratory birds, their nests and eggs. Consultations with the Fish and Wildlife Service (FWS) and State agencies are encouraged.	• If migratory birds are found on or near a potential site, support facility or an area of characterization activity, DOE will contact the USFWS to develop mitigative measures.	DOE projects an ability to comply because only minor impacts are expected and DOE will implement appropriate measures to mitigate impacts to migratory birds and/or their nests.
Fish and Wildlife Coordination Act, 16 USC Sections 661-666c	This Act mandates that wildlife conservation receive equal consideration with proposed projects that affect bodies of water.	• Act applies to projects involving modification, control, or impoundment of a body of water (for impoundments, surface areas must be 10 acres or greater). 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 DOI and State agencies, and include in project plan measures that prevent, mitigate, or compensate for losses of wildlife resources.	• Repository construction may result in local and temporary increased sediment discharge and turbidity in tributaries draining the dome area (Section 4.2.1.4). If the site is selected for characterization, DOE will continue consultations with the FWS and the State wildlife agency about potential impacts of project activities to fish and wildlife associated with surface waters and discuss the need for mitigative measures. • If wildlife conservation measures are required, mitigation or compensation plans will be incorporated into the project plan.	DOE projects an ability to comply because it will implement appropriate mitigative measures, if identified, by continuing consultations with FWS and the Mississippi Department of Wildlife Conservation.
Bald and Golden Eagle Protection Act, 16 USC Sections 668-668d (50 CFR Parts 13 and 22)	This Act prohibits possessing, killing, transporting, disturbing, etc., bald and golden eagles, their nests, or eggs.	Project activities must avoid negative impacts (including indirect effects) to bald and golden eagles, and their nests and eggs. If a golden eagle	• Bald eagles possibly occur in the dome area but are not expected to be found (Eco-Inventory Studies, Inc., 1983; Forest Service, 1983).	DOE projects it can comply with the requirements of the Act because DOE will implement mitigative measures, after consultation with the FWS and the Mississippi Department of Wild-

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Bald and Golden Eagle Protection Act, 16 USC Sections 668-668d (50 CFR Parts 13 and 22)	This Act prohibits possessing, killing, transporting, disturbing, etc., bald and golden eagles, their nests, or eggs.	Project activities must avoid negative impacts (including indirect effects) to bald and golden eagles, and their nests and eggs. If a golden eagle nest is found and must be moved, the Secretary of Interior may permit relocation of nest if it interferes with resource development or recovery plans.	• Bald eagles possibly occur in the dome area but are not expected to be found (Eco-Inventory Studies, Inc., 1983; Forest Service, 1983). • The golden eagle is known to occur throughout the State as a rare winter resident and has been observed in Perry County (BNI, 1982, ONWI-193). • The site will be surveyed for bald and golden eagles. • DOE will continue to consult with the FWS about appropriate mitigative measures for bald or golden eagles that may be affected by project activities.	DOE projects it can comply with the requirements of the Act because DOE will implement mitigative measures, after consultation with the FWS and the Mississippi Department of Wildlife Conservation, if they become necessary.
National Wildlife Refuge System Administration Act of 1966, 16 USC Sections 668dd-668ee (50 CFR Parts 25, 27, 28, and 29)	This Act establishes the National Wildlife Refuge System by consolidating authority over fish and wildlife conservation areas under the Secretary of Interior, FWS.	Project activities must not conflict with the protection and conservation purposes for which the refuge areas were established.	The Richton Dome project area is not located on existing or proposed National Wildlife Refuge System land (Aycock, 1985a). Mississippi Sandhill Crane National Wildlife Refuge is the closest refuge, located approximately 55 miles from the proposed site (Aycock, 1985b).	This statute is not applicable because existing or proposed land within the National Wildlife Refuge System is not close enough to be impacted.
Endangered Species Act of 1973, 16 USC Sections 1531-1543 (50 CFR 17.11 and 17.12, 17.94, 17.95, 17.96; Parts 222, 226, 227, 402, 424, 450, 451, 452, and 453)	Act prohibits Federal agencies from taking any action that would jeopardize the existence of endangered or threatened species or destroy critical habitat.	• DOE must determine if any listed (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 Regional Director, FWS, and follow the FWS procedures. An agency cannot endanger a protected species.	• The FWS has indicated that several endangered and candidate species may occur in the project area (Jordan, 1984). • No proposed species or designated critical habitat occur in the vicinity of the proposed site (Jordan, 1984). • A site inspection of areas to be disturbed by project activities will be conducted prior to site characterization to assess the potential for the occurrence of designated and candidate endangered species. DOE will consult with FWS on the results of the site inspection and discuss the need for a biological assessment.	DOE projects an ability to comply because actions will be taken in consultation with the FWS to preserve the continued existence of listed and proposed species. The DOE is committed to meet all regulatory requirements of this act.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Wild, Free-Roaming Horses and Burros Act, as amended, 16 USC Sections 1331-1340 (43 CFR Part 4700)	This Act protects all unbranded and unclaimed horses and burros on public lands administered by the BLM and the USFS.	Project activities must avoid harm (including indirect effects) to wild, free-roaming horses and burros on public lands.	Wild horses and burros under the jurisdiction of the BLM and the USFS do not occur at the proposed site or in the project area. The closest herds administered by the BLM are located in the western states of Nevada, Idaho, Utah, Wyoming, and Colorado (Gillas, 1985a; 1985b). The closest herds administered by the USFS are located in Texas, Okalhoma, Kansas, and Nebraska (Halverson, 1985).	The statute is not applicable because protected wild horses and burros do not occur in the project area.
Sikes Act, 16 USC Sections 670a et seq.	To develop conservation and rehabilitation programs involving the protection and enhancement of wildlife, fish, and game resources on certain Federal lands.	The Secretary of the Interior is responsible for developing, with prior approval of DOE, comprehensive plans for conservation and rehabilitation programs to be implemented on DOE land. State agencies may enter into cooperative agreements with DOI and DOE with respect to such conservation and rehabilitation programs.	Although the Act does not impose any requirements directly on DOE, DOE will consult with DOI to determine if a conservation and rehabilitation program is required.	DOE projects an ability to comply because it will consult with DOI and assist in preparation of any required conservation and rehabilitation plan.
<u>Air Quality and Noise</u>				
Noise Control Act of 1972, as amended by the Quiet Communities Act of 1978, 42 USC Sections 4901-4918 (E.O. 12088)	Federal agencies are to carry out their programs in a manner that promotes an environment free of noise that could jeopardize health or welfare.	DOE is required to comply with Federal, State, interstate, and local requirements for the control and abatement of environmental noise.	There are no Federal, State, local, or interstate standards that would be applicable to site characterization or repository construction, operation, or closure (Anderson, 1984; Henderson, 1984). As discussed in Sections 4.2.1.6 and 5.2.7, noise will emanate from equipment and from infrequent short-duration blasting, but will be mitigated to below EPA Health and Welfare Guidelines at nearby residences.	DOE projects an ability to comply because (1) analyses indicate noise levels will be kept below those that would jeopardize health or welfare (Sections 4.2.1.6 and 5.2.7), and (2) additional noise-control measures can be applied to reduce noise levels at nearby residences further, as needed.

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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Clean Air Act as amended, 42 USC Sections 7401-7642 (40 CFR Parts 50, 51, 52, 58, 60, 61, 124; Sections 81.300 and 81.400; E.O. 12088)	Act establishes air emissions limitations and air quality standards and requires states to develop a plan (SIP) of strategy for attaining and maintaining air quality standards. Authority for regulating sources of air emissions in Mississippi has been delegated to the State by the Federal EPA.	• DOE is required to comply with all Federal, interstate, State, and local requirements relating to the control and abatement of air pollution. • Sources of air pollution must comply with emissions standards and other requirements. In addition, air pollutant emissions must not cause national ambient air-quality standards to be exceeded. If emission rate of any criteria air pollutant from stationary sources is more than 250 tons/year, project must undergo Prevention of Significant Deterioration (PSD) review.	Since Mississippi has been delegated authority to administer the Clean Air Act, compliance with Mississippi Law will satisfy Clean Air Act compliance.	DOE projects an ability to comply because it will obtain all necessary permits and meet all applicable requirements. (See Mississippi Air and Water Pollution Control Law below.)
Air and Water Pollution Control Law, for Mississippi, Miss. Code Ann. Sections 49-17-1 to 49-17-43, 17-17-27(3), and 17-17-47. (APC-S-1,2,3)	Act establishes a statewide program for the prevention and regulation for pollution of the air.	• The proposed installation must be in accord with applicable requirements of National Standards of Performance for New Stationary Sources, called New Source Performance Standards (NSPS), National Primary and Secondary Air Quality Standards (NAAQS), National Emissions Standards for Hazardous Air Pollutant (NESHAPS), and Mississippi regulations, including the requirement that the facility be designed and equipped with the latest control technology. • Prior to the construction of any sources of air pollution, DOE must obtain a permit to construct from the Mississippi Air and Water Pollution Control Permit Board.	• Emission Inventory of criteria pollutants has been established for site characterization and repository construction and operation. Stationary source emissions are below the levels which trigger PSD requirements (250 tons per year). The steam plant is the only source that is regulated by NSPS. However, with a 124-million Btu/hr capacity, it is below the minimum size (250 million Btu/hr) necessary to trigger NSPS requirements (Section 5.2.5). • Other than construction-related fugitive particulate emissions, the only significant emissions are oxides of nitrogen (NO_x). Air quality estimates (offsite) show TSP and NO_2 concentrations during site characterization	DOE projects an ability to comply because it will obtain all necessary permits and meet all applicable requirements, including the requirement that it utilize the latest control technology for all sources of air pollution.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
		• DOE must also obtain a permit to operate the facility from the Permit Board.	and repository construction and operation would be below NAAQS. No sources of hazardous air pollutants are known, so NESHAPS requirements are not triggered. • Site characterization and repository engineering designs include plans for latest control technology on stationary sources and controls on fugitive dust emissions.	
<u>Cultural Resources</u>				
Archaeological Resources Protection Act of 1979, 16 USC Sections 470aa-470ll (36 CFR Part 296; 43 CFR Part 7)	Act protects archaeological resources located on U.S. public lands (includes most Federal lands) or Indian lands.	• DOE must determine if archaeological resources that may be damaged during project-related activities are present on Federal land. • Assessment and consultations with the State Historic Preservation Office (SHPO) are required if resources are discovered. • If excavation and removal become necessary, the Federal Land Manager having jurisdiction over the land must give permission.	• DOE will conduct surveys and complete consultations with SHPO, assess potential impacts on resources found, and take appropriate measures to avoid or protect the resources. Information on archaeological resources associated with site work will be recorded and reported. • For site characterization, a Programmatic Memorandum of Agreement (PMOA) among the DOE, the Advisory Council on Historic Preservation (ACHP), and the Mississippi State Historic Preservation Officer will be developed (Purcell, 1985).	DOE projects an ability to comply because DOE is committed to avoid or remove resources discovered in accordance with the Act and PMOA if resources may be affected during site characterization or repository construction activities.
National Historic Preservation Act of 1966, as amended, 16 USC Sections 470-470w-6 (36 CFR Parts 60 and 800; E.O. 11593); Historic Sites, Buildings and Antiquities	Acts protect districts, sites, buildings, structures, and objects significant in American history, architecture, archaeology, and culture that are included in or eligible for inclusion in the National Register.	DOE must request information from SHPO and study existing literature to determine whether or not project area contains any structure or object listed in or eligible for inclusion in the National Register. If resources are	• DOE has consulted with Mississippi SHPO (Neff, 1983; Neff, 1984a and b; McGahey, 1983). Archaeological surveys will be conducted by DOE in consultation with SHPO if the Richton Dome site is selected for site characteri-	DOE projects an ability to comply because no structures or objects eligible for the National Register have been identified on the potential repository site. Should future surveys identify eligible resources, DOE anticipates that it would be able to mitigate by avoidance or data recovery

Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Act, 16 USC Sections 461-467; Archaeological and Historic Preservation Act, 16 USC Sections 469-469c (36 CFR Parts 62, 63, 65, and 296; 43 CFR Part 7)		known to be in the area, or if requested by SHPO, DOE should survey the site to identify resources. If project area contains resources that are eligible for inclusion in the National Register, DOE must determine the effect that any project activities may have on the resource. If effect would be adverse, DOE must prepare a plan of mitigation and consult with the Advisory Council on Historic Preservation.	zation/repository. • For site characterization, a Programmatic Memorandum of Agreement (PMOA) between the DOE, the Advisory Council on Historic Preservation (ACHP), and the Mississippi State Historic Preservation Officer will be developed (Purcell, 1985).	any adverse impacts to these resources in accordance with the PMOA.
American Antiquities Act, 16 USC Sections 432 and 433 (25 CFR Part 261; 36 CFR Part 296; 43 CFR Parts 3 and 7)	Act protects historic and prehistoric ruins, monuments, and 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 Federal land, DOE must determine if project will adversely affect resources. • Secretary of DOI or DOA will have to grant permission to proceed before activities may be undertaken that could result in appropriation, excavation, injury or destruction to any historic ruin or antiquity.	• DOE will conduct surveys of project area and support facilities to identify resources and assess potential impacts on them, taking appropriate measures to avoid or institute a data recovery program for the resources. • For site characterization, a Programmatic Memorandum of Agreement (PMOA) between the DOE, the Advisory Council on Historic Preservation (ACHP), and the Mississippi State Historic Preservation Officer has been developed (Purcell, 1985).	DOE projects an ability to comply because DOE will avoid or institute a data recovery program for the resources discovered in accordance with the Act and as specified in the PMOA if resource may be affected during site characterization or repository construction activities.
American Indian Religious Freedom Act, 42 USC Section 1996 (36 CFR Part 296; 43 CFR Part 7)	Act protects and preserves Native American religions and practice.	• DOE must determine if project area is in an area related to Native American religious rites or is a sacred site of any Native American group. • If the site is in such an area, DOE should consult Native American leaders to determine if project would infringe on religious practices. If infringement is possible, DOE should consider alternatives; if no feasible alternative is avail-	• No Federally recognized Native American tribes exist in Perry County. Once the Bureau of Indian Affairs identifies State recognized tribes in the area, DOE will conduct further consultations with identified appropriate Native American Tribal leaders (Oxendine, 1984a and 1984b). If infringement on religious practice appears possible, DOE will consider alternatives and consult with the Office of Intergovernmental Affairs.	DOE projects an ability to comply because it will complete required contacts and consider alternatives if the site is in an area related to Native American religious rites or if the site is in a sacred area of any Native American group.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
		able, project should be reviewed by Office of Intergovernmental Affairs, and approved by the Secretary of Energy.		
<u>Hydrology and Water Quality</u>				
Federal Water Pollution Control Act, as amended by the Clean Water Act, 33 USC Sections 1251-1376 (40 CFR Parts 110, 116, 117, 121, 122, 123, 124, 125, 129, 230, 401, 403; 33 CFR Parts 209, 320, 323-327, and 330; E.O. 12088)	Act regulates pollution of the waters of the United States.	• DOE must obtain a National Pollutant Discharge Elimination System (NPDES) Permit for discharges from sediment retention basins and sewage treatment facilities planned for the exploratory shaft facility, and any discharges to waters of the U.S. from the the repository. Mississippi has been delegated authority to administer the NPDES program. • DOE must comply with Section 404 dredge and fill permit regulations. • Subject to certain conditions, activities such as core sampling, seismic exploratory operations, and plugs of seismic shot holes may be conducted under nationwide permits. In addition, under the nationwide permit system and subject to certain conditions, only notification of the district engineer is required when water (including wetlands) of less than 10 acres are affected. Impacts to wetlands greater than 10 acres would require a permit from the U.S. Army Corps of Engineers.	DOE will complete and submit NPDES permit and Section 404 dredge and fill permit applications as required. Final engineering design will be provided to submission of permit applications.	DOE projects it can meet Federal and State water pollution control requirements because engineering control measures will be applied to keep discharges within allowable limits and such measures will be applied to meet any applicable Section 404 dredge and fill permit requirements as described in Sections 4.1.2.2 and 5.1.2.3.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Air and Water Pollution Control Law for Mississippi, Miss. Code Ann. Sections 49-17-1 to 49-17-43, 17-17-27(3), and 17-17-47. (Miss. Water Quality Criteria and Wastewater Permit Regs.)	General Law to control air and water pollution. Regulations govern issuance of NPDES, underground injection control, and state permits. Criteria are established for maintenance of water quality in waters within Mississippi.	• Any person discharging into surface waters must apply to the Permit Board for an NPDES permit. If discharge is into underground waters, an underground injection control permit is required. If operating a treatment works with no discharge, a State permit is required. • Plans for proposed industrial treatment plant must be submitted to Mississippi Commission on Natural Resources for comment prior to construction, unless design capacity is 10,000 gal/day or less and does not involve EPA and State	DOE will complete and submit appropriate permit applications.	DOE projects an ability to comply f reasons outlined above (Clean Wate Act) and below (Safe Drinking Wate Act).
Air and Water Pollution Control Law (Continued)		grant or underground injection. The Commission must be advised in writing of type and capacity of system even if exemption applies. • Minimum water quality criteria, which apply to level of water quality standards that must be maintained after industrial discharges, are established. Specific criteria are established for public water supplies, which must meet requirements.		
Rivers and Harbors Appropriations Act of 1899, 33 USC Sections 401-413 (33 CFR Parts 209, 320, 322, 325, 326, 329, and 330); Bridge Act of 1906, 33 USC Section 491 et seq.; General Bridge Act of 1946, 33 USC Section 525 et seq. (33 CFR Parts 114 and 115).	Acts prevent any alteration or modification of the course, location, conditions or capacity of any channel of any navigable water of the U.S. without a permit. Construction of bridges is also regulated.	• DOE must obtain a permit from U.S. Army Corps of Engineers (COE) if fill material is put into navigable waters. • A permit is required from the Coast Guard for the construction of bridges over any navigable water. Obstruction of a navigable water is prohibited without a permit from the COE.	• Highway and railroad routes for the repository will require construction of several bridge and grade crossings. Such crossings along with other drainage crossing will affect navigable waterways under COE jurisdiction (5.1.2.2). DOE will initiate permitting procedures with the COE as appropriate.	DOE projects an ability to comply because it will meet COE requirements and there is flexibility in designing and constructing the required river and stream crossings.

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Safe Drinking Water Act, 42 USC Sections 300f-300j-10 (40 CFR Parts 122, 124, 141, 142, 143, 144, 145, 146, 147; E.O. 12088)	The purpose of this Act is to regulate public water supply systems and to prevent pollution of underground sources of drinking water.	• DOE must obtain an Underground Injection Control (UIC) Permit or utilize a licensed underground injection well facility, if underground injection is chosen as the method of disposal for brine or if other activities involve injection. • DOE must comply with all Federal, State, and local requirements regarding drinking water if a public water system is proposed. • Mississippi Bureau of Pollution Control (MBPC) is granted authority to issue UIC permits for Class I, III, IV, and V wells. • Federal agencies are prevented from granting assistance to any project that may contaminate an EPA-designated Sole Source Aquifer so as to create a significant health hazard.	• Brine- and salt-contaminated runoff generated at the exploratory shaft facility will be disposed of by injection at an existing licensed facility near Laurel, Mississippi, 30 miles from the site (Parsons Brinckerhoff/PB-KBB, 1984; Section 4.1.2.2). • Disposal of waste salt by brine injection is not a viable option due to the large volume of water required (Section 5.1.2). • Consultation with MBPC will determine if other project activities (e.g., freeze wall for shaft construction or well tests) will require a permit for a Class V well. • No EPA-designated sole source aquifers are nearby.	DOE projects the ability to comply because injection is not planned for salt disposal at the repository and because DOE will comply with permit requirements for Class V wells, if this permit is necessary. In addition DOE will comply with applicable State and local requirements regarding drinking water supply systems. (See Mississippi Safe Drinking Water Law below.)
Air and Water Pollution Control Law for Mississippi, Mississippi Permit Regulations, promulgated Mississippi Department of Natural Resources, Bureau of Pollution Control		• See Mississippi Air and Water Pollution Control Law and Federal Safe Drinking Water Act above for underground injection control (UIC) permit requirements.		

Table 6-2. Statutory/Regulatory Authorities and Requirements, Richton Dome Site
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Authority	Purpose and Intent	Requirements	Compliance Demonstrated/ Actions Planned	Projected Ability to Meet Requirements
Mississippi Safe Drink-Water Law, Miss. Code Ann. Sections 41-26-1 to 41-26-21 (Mississippi Primary Drinking Water Regulations; Water Quality Criteria).	Regulates public water systems and establishes Mississippi State Board of Health.	• Public water systems, defined as including a drinking water system regularly supplying at least 25 individuals, require a permit from the Mississippi State Board of Health. • Mississippi State Board of Environmental Health, Division of Water Supply, requires submittal of plans and specifications regarding proposed water supply; approval must be obtained prior to entering into financial commitment for beginning construction; detailed plans and sampling/monitoring scheme must be specified.	DOE will submit plans and specifications for any drinking water systems that will service at least 25 persons.	DOE projects an ability to comply since it will follow Mississippi requirements regarding the obtaining of necessary approval for any public water supply system at the site.

Table 6-3. Non-Federally-Derived State and Local Statutory and Regulatory Authorities, Richton Dome Site

STATE REQUIREMENTS

Land Use

State Parks and Forests
Miss. Code Ann.
Sections 55-3-1 *et seq.*
and 49-19-1 *et seq.*

Coastal Wetland Protection Law,
Miss. Code Ann. Sections 49-27-1
et seq., Coastal Zone Management,
Mississippi Code Ann.
Section 57-15-6

Mississippi Natural Heritage Law of 1978,
Miss. Code Ann.
Sections 49-5-141 to 49-5-157

Waste Disposal

Use of Salt Domes or other Geologic
Structures for Disposal of Radioactive
Waste, Miss. Code Ann.
Section 17-17-49

Nuclear Waste Storage and Disposal,
Miss. Code Ann.
Sections 57-49-1 to 57-49-43.

Ecology and Wildlife Protection

Fish, Game, and Bird
Protection and Refuges,
Miss. Code Ann.
Sections 49-5-51 to 49-5-51

Nongame and Endangered Species
Conservation Act,
Miss. Code Ann.
Sections 49-5-101 to 49-5-119

Table 6-3. Non-Federally-Derived State and Local Statutory and Regulatory Authorities, Richton Dome Site (Page 2 of 2)

Cultural Resources
Antiquities, Miss. Code Ann. Sections 39-7-3 to 39-7-41
Hydrology and Water Quality
Dam and Water Resources Management, Miss. Code Ann. Sections 51-3-1 *et seq*. and 51-4-1 et seq.
LOCAL REQUIREMENTS
There are no known local environmental requirements that apply to site characterization or repository construction and operation.

Table 6-4. Mitigation of Potential Adverse Environmental Impacts, Richton Dome Site

Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Water Quality:			
Surface Water			
Temporary increased sediment discharge and turbidity in nearby streams during siting (Sections 4.2.1.4.1 and 5.2.2.1). Effect on flow volume and rates due to stream diversion and channelization (Section 5.2.2.1). Possible degradation of surface water quality from salt/spoils pile runoff and windblown salt and dust during construction and operation (Sections 4.2.1.4.1, 5.2.2.1.1 and 5.2.2.1.2).	Use of sediment catchment basins and retention ponds during siting, construction and operation. Runoff collected in ponds will be periodically discharged off site if it meets regulatory requirements. Diking for runoff control, water spraying for dust control, covering of salt spoil piles, use of coffer dams (Sections 4.2.1.4.1 and 5.2.2.1).	Design criteria for runoff control structures should prevent release of contaminants. Ponding of surface runoff may reduce runoff to nearby streams, thus reducing flood levels. Control measures are expected to reduce windblown dust (EPA, 1978, AP-42). Diking and coffer dams will mitigate the effects of channelization (Sections 4.2.1.4.1 and 5.2.2.1).	DOE expects residual impacts to be acceptable because they will be limited to local and temporary increases in sediment loads prior to completion of sediment ponds, and windblown solids which will have a minor imperceptible impact on water quality (Sections 4.2.1.4.1 and 5.2.2.1).
Ground Water			
Interruption of the ground-water flow regime and effects on ground-water quality due to drilling activities and ground-water extraction during siting (Sections 4.2.1.4.2 and 4.2.1.4.3). Effects on ground-water quality due to possible leakage of salt-pile or mud-pit liners or fuel tank and windblown salt (Sections 4.2.1.4.2 and 5.2.2.2). Lowered potentiometric levels due to ground-water withdrawal for repository construction and operation, aquifer cross-contamination from hydraulic connections during construction (Section 5.2.2.2).	Use of water seals, collars, and shaft liners to vertically isolate aquifers to minimize contamination. Use of liners under salt piles, and in evaporation ponds to prevent leakage to aquifers. Ground-water monitoring wells and a leachate collection system will be installed to detect and pump out leakage (Sections 4.2.1.4.2 and 5.2.2.2).	Control measures should substantially reduce the probability and extent of any ground-water contamination. DOE will rely on early detection and cleanup if liner leakage develops (Sections 4.2.1.4.2 and 5.2.2.2).	DOE expects residual impacts to be acceptable because the potential volume of contaminated ground water will be small relative to the aquifer volume due to efficacy of the control measures, early detection by the monitoring system, and quick remedial action.
Air Quality:			
Increased particulate and NO_x emissions during ESF and repository construction will lead to increased concentrations of these air pollutants (Sections 4.2.1.3 and 5.2.5). Relatively minor air quality impacts will occur during repository operation and decommissioning (Section 5.2.5). Projected increases in TSP concentrations are based on fugitive dust emission factors which are assumed to be suitable for modeling TSP impacts (Section 5.2.5.3.2). These factors were developed from offsite measurements where soil characteristics such as silt and moisture content may differ from those existing at the site.	Water spraying, chemical suppressant application and salt pile management measures to reduce airborne particulates. Use of offsite electric power. Paving and cleaning of site access roads. Vehicle traffic restrictions and speed limits and minimizing the area of disturbed land will be employed (Sections 4.2.1.3 and 5.2.5). Freeze-hole drill rigs used for three months during ESF construction to be fueled by natural gas (or LPG) and fitted with NO_x reduction device (Section 4.2.1.3)	Water spraying and stabilization of soils are projected to reduce emissions of airborne dust and salt. Road cleaning and controls will reduce associated emissions. See Sections 4.2.1.3 and 5.2.5 (EPA, 1978, AP-42).	DOE believes that air quality impacts are acceptable because they are within regulatory standards established by Congress to protect human health and welfare (Sections 4.2.1.3 and 5.2.5).

Table 6-4. Mitigation of Potential Adverse Environmental Impacts, Richton Dome Site
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Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Cultural Resources:			
Direct impacts during siting and construction, and indirect impacts during siting, construction, and operation are not expected because there are no known sites eligible for the National Register of Historic Places on site (Sections 4.2.1.8 and 5.2.8).	Mitigation plans will be developed in consultation with the State Historic Preservation Officer and Advisory Council on Historic Preservation if any resources are discovered. Archaeological sites will be avoided by relocating activities whenever possible. Access to historic sites may be controlled (Sections 4.2.1.8 and 5.2.8).	The potential for discovering surficial cultural resources is low due to previous land disturbance in the area (Section 5.2.8.1). Mitigation plans will eliminate all direct impacts. Indirect impacts will be significantly reduced through the use of worker awareness programs (Sections 4.2.1.8 and 5.2.8).	DOE believes that residual impacts are acceptable because direct impacts can be eliminated and the residual indirect impacts will not result in the loss of significant amounts of cultural resources information.
Soils:			
Soil erosion, mixing of soil horizons, and disturbance of local topography and drainage patterns may result from siting, construction and repository activities. Soil contamination may result from spills, windblown salt, or leakage from retention ponds during construction and operation. Wind erosion of soils stripped of vegetation during siting and construction (Sections 4.2.1.5.1 and 5.2.1.2).	Soil ridging and banking, reseeding and mulching, and runoff diversion structures and retention ponds will be used. Water spraying, soil stabilization, salt and spoils pile management measures to reduce wind erosion of exposed soils. Nutrients and soil amendments where necessary to support vegetative growth when stripped subsoil is stabilized or redistributed (Sections 4.2.1.5.1 and 5.2.1.2).	Pond liners with leakage detection and recovery systems are projected to reduce the potential for soil contamination. Salt management measures are expected to eliminate soil contamination except in the immediate vicinity of the salt pile and transfer points. Water sprays are projected to reduce airborne particulate emissions in areas of exposed soil (EPA, 1978, AP-42). Revegetation measures should reduce wind erosion to approximately the undisturbed levels.	DOE believes that soil erosion and contamination impacts can be held to acceptable levels because effective engineering measures (liners, soil stabilization, revegetation) are planned to reduce these impacts.
Noise:			
Increased sound levels in areas around drilling sites and near earthmoving equipment during site characterization and repository constructien. Noise during some phases of construction will exceed EPA guidelines at the nearest residences. Temporary (6-12 days) increases in sound levels during shaft sinking due to blasting. Noise from repository operation is expected to be associated mainly with increased traffic during shift changes (Sections 4.2.1.6 and 5.2.7). Sound emission levels used in the analysis are believed to be accurate to ± 5 dB. Unfavorable wind and temperature gradient effects, which would increase noise propagation toward a sensitive receptor such as a residence are believed to be an infrequent occurrence.	Use of standard noise muffling devices on equipment. Blasting during daylight hours (0700 to 2200). Additional measures such as enclosure of stationary equipment, use of sound absorbing materials, construction of noise directive walls and baffles may be used to reduce impacts to nearby residences where appropriate. The noise modeling assumed standard equipment with no special quieting (Sections 4.2.1.6 and 5.2.7).	Control measures applied as necessary are expected to reduce noise to below EPA guideline values for rural areas with the exception of blasting.	DOE believes the noise impacts to be acceptable because few residences are expected to experience annoying levels of noise, and DOE has confidence that noise levels can be further reduced through the use of control measures. Blasting noise will be limited to two 6-12 day periods during shaft sinking.

Table 6-4. Mitigation of Potential Adverse Environmental Impacts, Richton Dome Site
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Potentially Significant Adverse Environmental Impacts	Control Measures to be Employed	Projected Effectiveness of Control Measures	Acceptability of Residual Impacts
Aesthetic Resources:			
Drill rig towers, shaft head frames, the meteorological tower, and mobile drill rigs will be visible from cleared areas in the vicinity. Impacts will occur due to the removal of vegetation (Sections 4.2.1.7 and 5.2.6).	Structures will be arranged and painted to blend with the surrounding environment. Disturbed areas that are not paved or graveled will be revegetated. The structures will be landscaped to blend with the topography and vegetative cover around the site (Sections 4.2.1.7 and 5.2.6).	Visual contrast in the area of the site due to disturbance of surface condition will probably be low because of recent clear cutting (Section 4.2.1.7.4). Control measures will limit visibility to those areas immediately adjacent to activity sites.	DOE believes residual impacts to aesthetic resources will be acceptable because the impacts are not considered unusual relative to those from other industrial facilities (Sections 4.2.1.7 and 5.2.6).
Biota:			
Some direct mortality to small animals and reptiles and displacement of wildlife may occur due to site clearing (Section 4.2.1.2) and increased human presence. Alteration of plant communities due to water quality changes may occur (Sections 4.2.1.2 and 5.2.4.1). Some aquatic habitat and biota will be lost through the loss of 6.6 hectares (16.3 acres) of intermittent wetlands during repository site preparation (Section 5.2.4.2).	Wetlands will be avoided whenever feasible. Salt management procedures and control structures will be employed to reduce salt deposition (Sections 4.2.1.2 and 5.2.4).	Control measures should limit impacts to temporary and localized displacement of biota (Sections 4.2.1.2 and 5.2.4).	DOE expects residual adverse impacts to be acceptable because they will be localized, and limited to ecosystems which are not unique, critical, or sensitive.
Land Use:			
Some forest land will be taken out of production if the repository is developed (Sections 4.2.1.1 and 5.2.3). Development of mineral resources within the controlled area, of low resource potential, will be prohibited (Section 4.2.1.1.2). Up to 50 residences on the dome could be displaced, with several of these residences being located within Richton's corporate limits. The community of Richton could be restricted in its ability to expand its residential areas to the west. Jurisdictions could lose some property tax dollars.	DOE can provide compensation to owners of affected resources where appropriate. All displaced residents would be compensated under the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970. DOE would provide Grants-Equal-to-Tax payments to affected jurisdictions to compensate for lost taxes. Residential development could be encouraged to the south of the town of Richton.	Compensation can mitigate the direct financial impact on owners of affected resources and properties. Grants-equal-to-tax payments should adequately compensate for loss of tax payments for taxing jurisdictions.	The change in land use over the dome cannot be mitigated, however, DOE believes that residual impacts will be acceptable because much of the forested land has already been cleared and is not unique to the area, and impacts to regional mineral resources will not be significant (Section 5.2.3.1). Loss of land for expansion west of the town of Richton will influence development of other parts of the community and vicinity. However, areas suitable for residential development are available within the town boundaries and to the south.

assessments, that the DOE will be able to meet all requirements, or that the requirements are not applicable to the proposed activities at the site. A favorable condition exists if a projected ability to comply is found. A potentially adverse condition exists if a major conflict with these requirements is projected.

Analyses of the impact provisions of this guideline are presented in Table 6-4, where impacts from EA Chapters 4 and 5 that are considered potentially significant and adverse are described and identified. Control measures that the project will use to avoid or mitigate impacts, and their projected effectiveness, are also presented in Table 6-4. A favorable condition is present if potentially significant adverse environmental impacts can be mitigated to an insignificant level. A potentially adverse condition is present if such impacts cannot be avoided or mitigated. A disqualifying condition is present if such impacts could not be mitigated to an acceptable degree, or if the quality of the environment in the affected area could not be adequately protected.

Other evaluations of the disqualifying conditions include (1) assessing the proximity of the site and repository support facilities with respect to boundaries of components of the National and State park systems, wildlife refuges, wilderness preservation areas, forest land, and wild and scenic rivers; and (2) assessing whether the activities would constitute an irreconcilable conflict between the facilities and the previously designated resource preservation use of such components.

6.2.1.6.2 Analysis of 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.

Evaluation. The DOE has identified the Federal and Federally delegated environmental statutory and regulatory requirements potentially applicable to the Richton Dome site. Table 6-2 lists the requirements, the compliance demonstrated, the actions planned, and the projected ability to meet the requirement at the Richton Dome site, based on available information and analyses.

The DOE projects the ability to meet environmental requirements applicable to the project area and the activities proposed to take place thereon (Table 6-2). The project area referred to in Table 6-2 refers to the project site and also encompasses project activities located off site (i.e., geotechnical activities), support facilities, access routes and utility corridors. The DOE cannot project an ability to meet all Federal and Federally mandated State requirements within time constraints because of the uncertainty in the time required to obtain all permits and approvals.

Table 6-3 lists non-Federally-derived state and local environmental statutes. The DOE intends to comply with all State and local environmental requirements not inconsistent with its responsibilities under the NWPA. The DOE intends to consult with State and local officials concerning sites that are recommended to determine the scope of requirements and to identify other regulations as appropriate.

The evidence indicates that the favorable condition is not present.

(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.

Evaluation. Potentially significant adverse environmental impacts, control measures employed to minimize the impacts and their effectiveness, and acceptability of the residual impacts are presented in Table 6-4. As outlined in Table 6-4, effective control measures are available to substantially reduce all potential adverse impacts. However, certain impacts, although acceptable from regulatory standpoint, cannot be mitigated "to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors." This is true, for example, of visual, air quality, noise, and ecological impacts. For example, there will be access corridors and repository facilities visible from off site. Therefore, visual effects will occur (Sections 4.2.1.7 and 5.2.6). Noise levels at two residences may experience increased noise levels depending on the exact location of the access road (Section 5.2.7.3.2). Applicable air quality standards (NAAQS) will be met, although the project will cause an elevation of NOx and TSP pollutant levels (Section 5.2.5.3). Removal of vegetation within access corridors will result in significant but localized habitat loss; approximately 6.6 hectares (16.3 acres) of intermittent wetlands will be lost during repository site preparation.

The evidence indicates that the favorable condition is not present.

6.2.1.6.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. Based on the information presented in Table 6-2, the DOE does not project a major conflict with applicable Federal, State, or local environmental requirements.

A potentially adverse condition is not present, because no major conflict with applicable Federal, State, or local environmental requirements is projected.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Potentially significant adverse environmental impacts and the control measures used to reduce these impacts are outlined in Table 6-4. Table 6-4 reflects that there is one projected significant adverse environmental impact, land use, including loss of a small portion of the town of Richton. These impacts can be mitigated as indicated in the columns headed "Projected Effectiveness of Control Measures" and "Acceptability of Residual Impacts" in Table 6-4:

1. Engineering control measures will reduce water quality impacts to minor, local, or temporary effects.

2. Air pollutant emission controls will reduce emissions to the point where impacts are within regulatory standards established to protect human health and welfare.

3. No cultural resource sites have been recorded at Richton Dome, and the potential for discovering surficial cultural resources is low due to previous land disturbance. Direct impacts on cultural resources can be eliminated, and indirect impacts reduced (through the use of training programs) to the level where no significant loss of cultural resource information is expected.

4. Soil contamination and erosion can be reduced to low levels by the use of pond liners, soil stabilization, and revegetation.

5. Noise impacts can be reduced by implementing appropriate noise control measures.

6. Facility and access corridor placement and design can reduce visual impacts so that repository and support facilities will not be particularly noticeable against the landscape.

7. Facility and access corridor placement and design can reduce impacts on biota to the point where they will be localized, limited to ecosystems which are not unique, critical, or sensitive, and will not adversely affect threatened and endangered species. Thus, there are significant land use impacts that can be mitigated.

8. Residents displaced by repository development can be relocated and compensated for any losses.

9. Restrictions to Richton residential, commercial, or industrial expansion due to presence of controlled area west of community will result in development in alternative areas currently available.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. Part of De Soto National Forest lies in proximity to the proposed repository site, about 4.8 kilometers (3.0 miles) north of the Richton Dome. No significant adverse environmental impacts on this or any other Federally protected lands are projected.

The evidence indicates that the potentially adverse condition is present.

(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.

Evaluation. The nearest State-protected resource is Paul E. Johnson State Park, located about 48 kilometers (30 road-miles) from Richton Dome. No significant adverse environmental impacts on this resource area are expected. Certain identified road and rail access routes to the site pass through the Chickasawhay Wildlife Management Area, which is used by the State under a cooperative agreement with the U.S. Forest Service. This area is not a State-protected resource as it is still owned and managed as National Forest Land by the U.S. Forest Service.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. No cultural resource sites have been recorded at the Richton Dome site and the potential for discovering surficial cultural resources is low due to previous land disturbance in the area (Section 5.2.8). No significant Native American resources are presently known to exist at or in proximity to the site. Consequently, no significant adverse environmental impacts on significant Native American resources or sites of unique cultural interest are projected.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. There are no known or designated critical habitats for threatened and endangered species that could be compromised by the repository or its support facilities.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.6.4 Analysis of Disqualifying Conditions.

(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.

Evaluation. Potentially significant adverse impacts and the control measures to be employed to minimize the impacts are presented in Table 6-4. Table 6-4 also documents the projected effectiveness of control measures and the DOE's judgment regarding the acceptability of the residual impacts.

The DOE believes that the quality of the environment can be protected in the affected area and that all projected environmental impacts can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors. This is shown in Table 6-4.

The evidence does not support a finding that the site is disqualified.

(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.

Evaluation. During the site selection process, all such lands were specifically excluded from consideration as potential repository sites (Section 2.2). Consequently, no part of the site is 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, and transportation and utility corridors to the site can be selected so they do not pass through such lands.

The evidence does not support a finding that the site is disqualified.

(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource preservation use 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 protection at the time of the enactment of the Act.

Evaluation. The closest such Federal land designated for resource preservation is the De Soto National Forest, located about 4 kilometers (2.5 miles) north of the proposed boundaries of the site. The presence of a repository would not be expected to conflict irreconcilably with the previously designated use of any component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, the National Forest Lands, or any comparably significant State-protected resource dedicated to resource preservation at the time of enactment of the Nuclear Waste Policy Act of 1982.

The evidence does not support a finding that the site is disqualified.

6.2.1.6.5 Conclusion for Qualifying Condition. Assessments of what is known about the site and affected area and the potential impact of preclosure repository activities provide reasonable assurance that requirements for the protection of the quality of environment can be met at the Richton Dome site.

Both favorable conditions for environmental quality are not present because potential significant adverse environmental impacts can be mitigated, but not always to an insignificant level, by using reasonable measures and because the DOE may not meet all requirements within time constraints (Section 6.2.1.6.2).

Based on analysis of potential impacts on air quality, water quality, cultural resources, biota, land use, noise, and visual aesthetics, one of the six potentially adverse conditions for environmental quality is present because the site is proximate to a unit of National Forest land; the other five potentially adverse conditions are not present for the following reasons:

1. No major conflicts with applicable environmental requirements are projected.
2. Projected significant adverse environmental impacts can be avoided or mitigated.
3. No significant adverse effects on State-protected resource areas are projected.
4. No significant adverse effects on Native American or unique cultural resources are projected.
5. There are no known critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.

None of the disqualifying conditions is present for environmental quality at the Richton Dome site. This finding is reached because:

1. The DOE believes that the quality of the environment in the affected area can be adequately protected, and projected environmental impacts can be mitigated to an acceptable degree.
2. No part of the restricted area or repository support facilities lies within Federally protected lands.
3. The restricted area and repository support facilities will not conflict irreconcilably with resource-preservation use of Federal or State lands dedicated to resource preservation (Section 6.2.1.6.4).

Evaluation of Part 2 of the Environmental Quality, Socioeconomic, and Transportation Guidelines is presented in Section 6.2.2.2.1. This evaluation indicates that from the environmental perspective (and the others), the evidence does <u>not</u> support a finding that the site is not likely to meet qualifying condition 9.60.5-1(a)(2).

Therefore, the evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition (Level 3).

6.2.1.7 Socioeconomic Impacts, Guideline 10 CFR 960.5-2-6

The objective of the Technical Guideline on socioeconomic impacts is to ensure that any significant adverse impacts can be offset by reasonable mitigation or compensation.

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

6.2.1.7.1 <u>Statement of Qualifying Condition</u>.

> 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.

Evaluation Process. The evaluation process consisted of (1) establishing baseline conditions with respect to the socioeconomic parameters identified in the guideline; (2) estimating total work force requirements for repository activities; (3) estimating the in-migrating portion of the work force and the associated increase in secondary labor demand; and (4) assessing changes in the socioeconomic conditions attributable to preclosure activities and the potential impacts to the projected socioeconomic environment without the repository.

Relevant Data. The existing socioeconomic profile (demography, labor force, community facilities, and other characteristics) of the region is discussed in Section 3.6. Specific socioeconomic and other related impacts from site characterization and repository development are discussed in Sections 4.2.2 and 5.4, respectively. An analysis of potential impacts is also presented in Section 5.4.

Assumptions and Data Uncertainty. The socioeconomic study area for the Richton Dome site includes Forrest, George, Greene, Jones, Lamar, Perry, Stone, and Wayne Counties. The total 1980 population of the eight-county region within an 80-kilometer (50-mile) radius of the Richton Dome was 215,590 inhabitants. The populations of urban areas located in proximity to the Richton Dome site are provided in Section 3.6.1. Socioeconomic impact projections are based on the current labor force estimates discussed in Section 5.4. Changes in the level of in-migration, employment, service needs, fiscal structure, and social structure depend heavily on labor force estimates. To estimate total impacts to the study area, these estimates do not assume any significant measures taken to raise the local hiring potential, such as training programs (see Section 5.4). In addition, the ONWI Population In-Migration Model uses population and employment multipliers that are based on current literature, other project data, and professional judgment. Analyses of socioeconomic impacts are based on existing conditions at the site area.

A major assumption of the present assessment is that since the delivery of services such as water and sewage treatment is related to households, there will be adequate service capacity where housing capacity is adequate.

Analysis. An evaluation of socioeconomic impacts attributable to repository development is presented in Section 5.4.

6.2.1.7.2 Analysis of Favorable Conditions.

(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.

Evaluation. During the peak repository construction period, the projected net change in total population within commuting distance of the site is less than 1 percent of the baseline population (see Section 5.4). This level of population increase would not cause significant disruption of community services. In counties projected to receive project-related in-migrants, housing capacity is projected to be adequate even after project-related housing needs are met. Based on the assumption that the delivery of services such as water and sewage treatment is related to households, adequate service capacity is expected. Other specific impacts to the affected communities are analyzed in Chapter 5 (Section 5.4). This analysis examines potential impacts on a regional level in order to provide an overview of total impacts for the study area.

The evidence indicates that the favorable condition is present.

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

Evaluation. The local labor force could account for 60 percent of the peak repository-related work force (Section 5.4.2.1). Thus, a certain portion of the repository work force would be hired from outside the study area. This estimate is based on the assumption that no extraordinary measures are undertaken to increase local hiring.

The evidence indicates that the favorable condition is not present.

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

Evaluation. The projected annual local employment growth rate attributed to repository-related activities is 0.10 percent of total employment in the socioeconomic study area, which will favorably augment the baseline annual growth rate of 1.1 percent. The peak of repository-related employment is projected to supply work for about 1,300 local residents who currently reside in the eight-county study area (Section 5.4). This local employment peak, which includes direct and indirect jobs, occurs during the operation phase.

Direct local material purchases attributable to the repository construction phase are projected to average about 5.3 million dollars per year. This would result in an estimated 0.5 percent average annual increase in the area's total retail sales (Section 5.4).

Construction of the repository will result in an increase in revenues from property taxes, sales taxes, and user fees. Property tax revenues will increase in those jurisdictions where workers choose to settle, and where residential and commercial real estate development occurs, thus increasing the amount of taxable property. Construction of the repository, and related salaries, will increase the personal income in the area, resulting in greater sales tax revenues from this source. Sales tax revenues will also increase from repository supplies that are purchased locally. User fees are related to specific services such as water supply or wastewater treatment. With the increase in project-related population, the revenues from user fees will increase. Section 5.4.5.1 includes information on intergovernmental transfer payments which offset government revenue loss due to the Federal purchase of land and the increased demand for services. These payments will include (1) grants equal to tax payments, (2) impact mitigation funds, and (3) impact planning grants. The actual amounts of tax revenues cannot presently be estimated.

The existence of improved community services will be dependent on the quality of services desired in each community. This is a policy question to be determined by local officials.

This guideline evaluates the net conditions of the economy of the affected area. The analysis has shown that the repository will provide increased employment, business sales, and government revenues. Each of these interrelated economic indicators indicates an overall economic impact in the affected area.

The evidence indicates that the favorable condition is present.

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

Evaluation. For this evaluation, primary sectors of the economy are defined as those which contribute to the majority of employment in the affected area. Based on employment, the primary sectors in the affected area are manufacturing, with 21 percent of the employment; government, with 25 percent of the employment; and trade, with 22 percent of the employment.

Disruption is defined here as a substantial loss of employment in a sector because of the repository. The repository and related demands for goods and services would not affect those sectors exporting products outside the region. The manufacturing sector generally exports products outside of the study area, and the majority of this market demand would not be affected by the repository. Employment in the trade and government sectors is likely to increase for reasons set forth under condition (3) above, namely increased wages, increased direct local purchases, 0.5 percent increased average annual sales, and increased service demand. Therefore, no substantial loss of employment is estimated in the primary sectors.

The evidence indicates that the favorable condition is present.

6.2.1.7.3 Analysis of Potentially Adverse Conditions.

(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.

Evaluation. This analysis is performed by drawing on the baseline condition of Chapter 3 and repository-related impacts identified in Chapter 5. Regional housing capacities within counties receiving the project-related in-migrants are projected to be adequate. Because the availability of community services generally parallels housing availability (Section 6.2.1.7.2 [1]), these services are also expected to be adequate in the affected area. While the favorable condition focuses on impacts to the study area, this potentially adverse condition addresses potential impacts on services, housing, and finances at the community level. An indicator for the potential for such impacts is the rate of repository-related population growth in relation to its projected baseline growth.

For this analysis, Richton is the community of concern for the Richton Dome site because it is the community where the difference is expected to be the greatest (see Section 5.4.1 for a discussion of communities in the impact area and their projected repository-related population increases). The town of Richton is projected to have in 1995 a cumulative repository-related growth of 37 percent over 4 years. Although an annual average of this growth rate is higher than the 6 percent growth rate projected for Richton's baseline population between 1990 and 1995 (see Table 3-36), a significant disruption is not expected. There is some uncertainty associated with estimating how a community will adapt to change since many factors are involved, such as the response of public service providers and expansion of the private sector. An extenuating circumstance which may offset the potential for disruptions to community services is the fact that several services are provided by the county and/or neighboring communities, such as the hospitals and the mental health center (see Section 3.6.3). Housing is provided by the private sector and can be expected to respond to market demands. Impacts on finances are not expected to be disruptive, as described in Section 6.2.1.7.1(3).

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. This condition is expected, as shown in the analysis of favorable conditions (2) in Section 6.2.1.7.2. The local labor force could account for 60 percent of the peak repository work force. Thus, the remaining repository work force would be hired from outside the study area.

The evidence indicates that the potentially adverse condition is present.

(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.

Evaluation. No need to purchase or acquire water rights exists. Water for the repository preclosure activities is expected to be available from local ground-water resources. No planned study-area development that would be affected by the water use projected for the repository has been identified.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. As shown in the analysis of favorable condition (4) of Section 6.2.1.7.2, a major disruption of the primary sectors is not expected.

The manufacturing sector generally exports products outside of the study area, and the majority of market demand would not be affected by the repository. The trade and government sector employment is likely to increase based on a projected increase in wages, local purchases, and service demands. Therefore, no substantial loss of employment is estimated in the primary sectors.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.7.4 Analysis of 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.

Evaluation. Ground-water resources are adequate to meet both local and repository needs (Section 5.2.2.2). No surface water will be withdrawn or consumed (Section 5.2.2.1). Repository operations are expected to have negligible effects on the quality of regional groundwater and surface-water resources (see Section 5.2.2).

The evidence does not support a finding that the site is disqualified (Level 1).

6.2.1.7.5 Conclusion for Qualifying Condition. The only potentially adverse condition noted under this guideline is a projected inadequacy of a locally available labor supply for all aspects of repository development. A significant disruption of regional community services or primary economic sectors is not expected, and a projected increase in employment and sales is expected. The amount of in-migration can be reduced by local job training. The disqualifying condition is not found because it is expected that water supplies will not be affected and that there will not be impacts to water quality.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.1.8 Transportation, Guideline 10 CFR 960.5-2-7

The objective of the transportation guideline is to ensure that proper consideration is given to the transportation of waste to a repository site. This transportation could affect the health and safety of the public, the environment, and the cost of waste disposal. The guideline requires the evaluation of a site's proximity to adequate highways and railroads, the characteristics of access routes from existing highways and railroads to the site, the costs and other impacts of designing and constructing the access routes, and the impacts of transporting waste over the access routes. The guideline indirectly requires consideration of proximity to the sources of waste because one of the favorable conditions is stated in terms of a comparison of costs and risks among sites.

This guideline includes a qualifying condition, nine favorable conditions, and four potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.2.1.8.1 Statement of 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.

Evaluation Process. Transportation access routes from the local and regional network were examined to determine viable routes for repository transportation requirements. This evaluation process includes an examination of (1) conflicts with protected Federal and comparable State lands, (2) construction methods using available technologies, (3) compliance with the DOT and the NRC requirements, (4) potential for causing unacceptable risks to public health and safety, and (5) mitigation of environmental and transportation infrastructure impacts. To ensure that all sites were evaluated in a consistent manner, a common set of criteria were developed by the DOE. These criteria were quantified and were also stated in the evaluation of each guideline; they are further discussed in Appendix A.

The nationwide sources of waste along with types and quantities of waste destined for the repository were estimated and are summarized in Appendix A. Local highway and railroad access routes from existing elements of the national transportation system to the site were identified to examine types of impacts that might be experienced. Where the evaluation requires comparison with other sites, the comparison is given in Chapter 7.

Relevant Data. The existing transportation system in the vicinity of the site is presented in Section 3.5. A description of the rail and highway access routes used to evaluate the site against the guideline, as well as transportation impacts and transportation route adequacy, are discussed in Sections 4.2.1.10, 5.1.2.2, 5.3.1, 5.3.2., and 5.3.3. Data used in the evaluation are summarized in Table 6-5.

Assumptions and Data Uncertainty. Access to the site from I-59 and the regional rail system would begin at Laurel and extend southward to the site, a distance of approximately 42 kilometers (26 miles) by highway and 42 kilometers (26 miles) by rail. Mississippi State Route 15 from Laurel is assumed to be the highway route to the site. It is assumed that repository personnel would operate the railroad over new trackage constructed on the abandoned ICG right-of-way between the site and an existing common carrier rail line at Laurel. Protected Federal and State lands that are near the site and the transportation access routes are described in Section 3.4.1. Meteorological data for the area are described in Section 3.4.3. Radiological and nonradiological risks to the public health and safety from nuclear waste transportation are discussed in Section 5.3.1.

The analysis is based on transportation facilities and conditions existing in 1984. Rail and highway traffic volumes and patterns could change by 1998, which in turn could result in construction of new facilities, abandonments, and changes in maintenance practices and physical condition of facilities.

Cost data are given in 1984 or 1985 dollars as noted. No land-acquisition costs are included. The alternative access routes are used only as a basis for assessing the impacts associated with nuclear waste transport to the site. Before preferred routes are selected, detailed studies and evaluation and consultation with the State and local officials will be required.

Analysis. The access routes connecting the repository site with the rail and interstate highway systems are described in Section 5.1.2.2. The design, engineering, and construction of the access routes will employ conventional civil highway and railroad engineering practices. No unique technologies are required. Transportation-related construction and operation will be carried out in a manner that protects the public health and safety and environmental quality.

Table 6-5. Site Transportation Data, Richton Dome

REPOSITORY ACCESS ROUTES - NEW CONSTRUCTION[a]	Truck	Rail
Length - Miles	4	26
Terrain Description	Gently Rolling	
Number of Tunnels	None	None
Number of Bridges	1	16
Number of River/Lake Crossings	None	None
Acquisition of Private Land Required	Yes	Yes
Overall Cost - $ Millions[b]	3	16
EXISTING HIGHWAY/RAILROAD NETWORK[a]		
Length of Upgrade - Miles	23[c]	0
Cost of Upgrade - $ Millions[b]	5.7	0
Distance to Interstate Highway/ Mainline Railroad from Access Route - Miles	22	0
TRANSPORTATION OPERATIONS - AUTHORIZED SYSTEM[d]		
Total Loaded Vehicle-Miles Traveled - Millions	96.4	17.7
Life Cycle Cost - $ Millions[e]	936	982
LIFE CYCLE RISKS - NON-RADIOLOGICAL		
Number of Injuries	240	17
Number of Fatalities	19	1.8
RADIOLOGICAL - NUMBER OF LCF'S		
Normal Conditions	6.3	0.2
Accidents	0.03	0.02

(a) From Section 5.1.2.2
(b) 1984 Dollars; land acquisition costs not included
(c) Includes 1 mile of county road from Mississippi State Highway 42
(d) From Section 5.3.1 and Appendix A
(e) 1985 Dollars

6.2.1.8.2 Analysis of 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.

Evaluation. In application of the guideline to determine the presence of the above favorable conditions, the following criteria have been used:

1. Routes that are short and economical to construct (less than 16 kilometers [10 miles] and less than $10 million, respectively) are considered favorable.

2. The acquisition of land for access routes that cross private land will most likely require condemnation proceedings.

3. The need for tunnels or bridges along an access route is considered unfavorable. However, the number of cuts and fills over generally flat terrain is considered insignificant.

4. Generally flat terrain is considered favorable.

5. Passing through local cities and towns is considered unfavorable if the population of the city or town in an incorporated area is greater than 2,500 people, or if the population density is greater than 1,000 people in a 2.6-square-kilometer (1 mile by 1 mile) area of the city or town.

In applying the above criteria, both highway and railroad access route characteristics must be favorable to consider the site favorable with respect to each condition. If any one of the alternative routes does not meet the favorable condition, a "not present" finding will be made. However, the presence of any one of the five conditions is sufficient for a determination of favorability on the overall group of five.

At the Richton Dome site, the railroad access route will be relatively expensive ($16 million) to construct because of the distance involved (42 kilometers [26 miles]). However, the highway access route new construction is short (6 kilometers [4 miles]) and is estimated to cost approximately $3 million. Rights-of-way for both truck and rail access routes will cross private land and Federal condemnation proceedings may be required. The railroad access route will require reconstruction of a number of small bridges, but the terrain is generally flat. On Mississippi State Route 15 leading to the access route, upgrading of several bridges will be required. Alignments will not include sharp curves or steep grades. The rail access route will pass through the town of Laurel, whose population and population density are greater than the criteria above.

Based on the above information, the evaluation of access route characteristics is summarized as follows:

Route Characteristic	Finding
Short and economical to construct	Not present
Federal condemnation not required	Not present
Cuts/fills/tunnels/bridges not required	Not present
Free of sharp curves/steep grades	Present
Local cities/towns bypassed	Not present

Because the guideline condition requires only one of the characteristics to be present, the evidence supports a finding that the overall favorable condition on access route characteristics is present.

The evidence indicates that the favorable condition is present.

(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.

Evaluation. In application of the guideline to determine the presence of this favorable condition, the distance from the outer end of the newly constructed access route to the nearest highway or railroad that does not need significant upgrading is considered. If such distance is less than 16 kilometers (10 miles) and upgrading cost is less than $10 million for each of the highway and railroad routes, the favorable condition is present.

At the Richton Dome site, significant upgrading of Mississippi State Highway 15 and local county roads will be required at several points. A total of 37 kilometers (23 miles) of upgrading, costing an estimated $5.7 million, is required. This includes upgrading along 35 kilometers (22 miles) of Mississippi State Highway 15 and 2 kilometers (1 mile) of upgrading on an additional access road for Mississippi State Highway 42. Because the access rail route extends all the way to a Class I railroad in Laurel, no significant upgrading of the local railroads in Laurel is needed.

The evidence indicates that the favorable condition is not present.

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

Evaluation. In application of the guideline to determine the presence of this favorable condition, the distance from the outer end of the newly constructed access route to the nearest interstate highway and mainline railroad is considered. If such distance is less than 48 kilometers (30 miles) for both the highway and railroad routes, the favorable condition is present.

At the Richton Dome site, the distance from the highway access route to I-59 is approximately 35 kilometers (22 miles) via Mississippi State Highway 15. The distance from the end of the repository rail access route at Laurel to the mainline railroad is zero.

The evidence indicates that the favorable condition is present.

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

Evaluation. In application of the guideline to determine the presence of this favorable condition, the number of interchanges expected within the region, based on routine deliveries in regular freight service from various points in the United States, is considered. Interchange points are important because radiation exposure, even though very low, is related to rail-car stopped time. A radius of 200 kilometers (125 miles) around the potential repository site is used to define the "regional railway system" in which interchange points are counted. This is believed to be a large enough area to include the convergence of all major rail lines from points throughout the United States that could be used for nuclear waste traffic. Interchange points include points where different railroads exchange cars, where the same railroad switches cars on its own system from one train to another, and where crew changes are made. The one site with the fewest interchange points is considered to have the favorable condition present. A comparison with other sites is given in Chapter 7.

Four Class I carriers serve the 200-kilometer (125-mile) zone around the Richton Dome site. These carriers serve the entire southeast United States and connect with other major systems serving virtually the entire United States. Seven route combinations using these four carriers are identified for the analysis. These routings would allow waste to enter the region from any conceivable direction or shipment origin. These routes are displayed in Table 6-6 along with the type and number of interchange points per routing.

No judgment is made with respect to the most likely route and corresponding number of interchanges. However, Table 6-6 shows that the total number of all interchanges per routing ranges between two and four regardless of the route actually used.

The evidence indicates that the favorable condition is not 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.

Evaluation. The estimates of national life-cycle costs and risks associated with nuclear waste transport are summarized in Table 6-5. Regional risks were also estimated and are discussed in Section 5.3.1. The purpose of the analyses was to provide conservative estimates of the risks and costs. These costs and risks are shown in Table 6-5. More details regarding the basis for these numbers are included in Appendix A. In the evaluation of sites against this condition, only one site will have the favorable condition present. As indicated in Appendix A and Chapter 7, the Richton site has the lowest costs and risks. A comparison with other sites is given in Chapter 7.

The evidence indicates that the favorable condition is present.

> (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.

Evaluation. The primary criteria used for the selection of highway carriers are whether or not the carrier has authority to haul nuclear (or nuclear-related) commodities and whether the carrier can offer direct service between nuclear power plant sites and the potential repository site. There are two categories of motor carriers that could potentially meet these requirements.

1. Special commodity, irregular route carriers who have nationwide authority. These carriers offer specialized service for specific commodities. The U.S. Interstate Commerce Commission (ICC) often grants operating authority to offer this service between points in most of the contiguous United States. Carriers with authority to haul either radioactive materials or hazardous materials are automatically included in this group. Those with authority to carry either nuclear components or explosives are also included. It is assumed that these carriers would have the experience to justify ICC approval to include radioactive materials in their operating authority. Seven highway carriers were found to have such authority.

2. General commodity, regular route carriers that have authority to serve the town closest to the repository site and also authority to serve numerous points in other

Table 6-6. Richton Dome Site Railway System Interchanges

Possible Routes	No. of Potential Interchanges in 125-Mile Radius per Routing: Inter Carrier	Inter Train	Crew	Total
SOU (Southbound)-Meridian-SOU-Laurel-RRR	1	-	1	2
SOU (Northbound)-New Orleans-SOU-Hattiesburg-SOU-Laurel-RRR	2	-	-	2
ICG (Southbound)-Jackson-ICG-Hattiesburg-SOU-Laurel-RRR	2	1	-	3
ICG (Southbound)-Jackson-ICG-Newton-G&M-Laurel-RRR	2	1	-	3
ICG (Southbound)-Jackson-ICG-Meridian-SOU-Laurel-RRR	2	1	-	3
L&N (Westbound)-Flomaton-L&N-Mobile-ICG-Hattiesburg-SOU-Laurel-RRR	3	1	-	4
BN (Southbound)-York-SOU-Meridian-SOU-Laurel-RRR	2	-	1	3

Note: Intercarrier and intertrain interchanges normally also involve a crew change, but are counted as a single "interchange."

Abbreviations:
SOU - Southern Railway
ICG - Illinois Central Gulf
G&M - Gulf and Mississippi
L&N - Louisville and Nashville
BN - Burlington Northern
RRR - Repository Railroad

States. These carriers meet the criterion of offering direct service between numerous States in which nuclear facilities are located and the prospective repository location. Those general commodity carriers with authority to carry hazardous materials and that participate in the American Trucking Association (ATA) Hazardous Materials Tariff are included in this group. Also, carriers that have a special commodities division within their organization are included. The assumption here is that these carriers have the experience and equipment necessary to offer the specialized service required for nuclear waste transport and that ICC authority could be obtained for nuclear waste since the carrier already has authority to serve the repository location. Eight highway carriers were found to have such operating authority servicing the region under consideration.

Thus, a total of 15 highway carriers were identified to have the capability to handle waste shipments to the repository. This number may change frequently between now and 1998; however, a multiplicity of highway carriers are expected to be available and willing.

The primary criteria for rail carriers are that they be Class I carriers (defined by the ICC as having operating revenues of over $50 million annually) and have mainline tracks within a 200-kilometer (125-mile) radius of the potential repository site.

There are four Class I railroads that have mainline track within the 200-kilometer (125-mile) radius of the Richton Dome site.

1. Southern Railway (SOU). Southern offers service throughout the southeastern United States with major gateways to other carriers in Washington, D.C., Cincinnati, St. Louis, Memphis, and New Orleans. Also, SOU is now a subsidiary of Norfolk & Western Railway available to offer direct service from a larger network. The mainline SOU route to New Orleans will likely be a major corridor of nuclear waste traffic from the northeast and middle Atlantic states since the line is direct and interchanges within 48 kilometers (30 miles) of the potential site with the delivery carrier, the ICG.

2. Illinois Central Gulf (ICG). The ICG is one of the rail carriers that actually provides service to the area near the potential repository. Generally, the ICG system operates from Chicago and the Midwest south throughout the Mississippi Valley to Gulf ports. The ICG can offer service to nuclear waste traffic from the Great Lakes area, the Midwest, and the West via interconnection with other major rail systems in Chicago, Kansas City, St. Louis, Memphis, and Shreveport.

3. Seaboard System Railroad (SSR). The Louisville & Nashville Railroad (L&N), a component of the Seaboard System, serves points throughout the mid-South from Chicago and Cincinnati south to New Orleans. The L&N also serves Mobile, Alabama, and interchange with the ICG. In addition, the L&N has access to the rest of the Seaboard network as well as the entire Chessie system offering numerous points of interchange with other major carriers serving most nuclear facilities.

4. Burlington Northern Railroad (BN). The BN generally serves the Pacific Northwest and the northern tier of states with direct lines through the Midwest to Gulf ports in Galveston, Mobile, and Pensacola. The line from Memphis to Mobile and Pensacola is a potential rail route for nuclear waste since it interchanges with both the SOU and L&N within the 200-kilometer (125-mile) zone in Mississippi.

There are no navigable waters that serve the Richton Dome area directly. However, inland water carriers could eventually play a role in the transportation system available to serve the repository. The completion of the Tennessee-Tombigbee River System (Ten-Tom) allows barge service from the Midwest to points in South Alabama that are less than 97 kilometers (60 miles) from the Richton Dome site. Barge service from the Great Lakes region to Memphis, Tennessee, then via rail to the Richton area may also be viable. Water traffic from East Coast points could also be handled at the Gulfport, Mississippi, or Mobile, Alabama, ports where direct rail lines are available to Beaumont, Mississippi. Potential water transportation alternatives are further discussed in Appendix A.

The number of water carriers that could provide service via the Tennessee-Tombigbee or Gulf ports is large, and there are few restrictions on serving any given market or port area. Consequently, any water carrier that generally operates in the Gulf and Tennessee-Tombigbee-Mobile-Warrior River systems could potentially serve the Richton area through intermodal service with the railroad.

In general, highway carriers have expressed considerable interest and willingness to offer nuclear waste transportation services, and several are now actively engaged in such business. The railroads, through their trade association (Association of American Railroads), have expressed, in the past, some reluctance to haul nuclear waste. However, more recently, it is no longer a matter of willingness, but a matter of services, conditions, and appropriate rates that needs to be resolved. See Appendix A and Appendix Section C.2.4.1 for more information on this subject.

The evidence indicates that the favorable condition is present.

(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.

Evaluation. This guideline favorable condition requires the consideration of State or local transportation rules or ordinances that are inconsistent with Federal regulations and would be an impediment to transportation of nuclear waste to the repository.

Since the Department of Transportation (DOT) regulation of highway routing of radioactive materials (49 CFR 177.825) (HM-164) has been established as valid by the U.S. Supreme Court, the only "legal impediment" is a State or local rule that renders compliance with 49 CFR 177.825 impossible, but is found not to be preempted under provision (112[b]) of the Hazardous Materials Transportation Act (HMTA). If such a finding cannot be made, any State or local rule that prevents or seriously impedes compliance with 49 CFR 177.825 is preempted by the HMTA (112[a]). Because State or local laws or regulations restricting the transport of nuclear waste that are inconsistent with either the HMTA or the DOT's regulations issued thereunder are preempted by the HMTA, such laws or regulations in the affected or adjoining States are not considered legal impediments. A more extensive discussion is given in Appendix Section C.2.4.1.

The evidence indicates that the favorable condition is present.

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

Evaluation. The Mississippi Natural Disaster Preparedness Plan (Mississippi Emergency Management Agency, 1983) covers State planning for all types of natural disasters. Part Two of the plan includes 26 annexes dealing with specific areas, one of which covers hazardous materials (Annex P). Annex P covers emergency response planning for "hazardous materials at industrial plants and the transportation of hazardous materials through the state." Radiological materials are included as a hazardous material in the definitions of Annex P, and specific contacts are provided in case of accidents involving radiological materials. Thus, Annex P of the State Natural Disaster Plan covers radiological transportation emergency in the context of overall hazardous material planning. In addition to the Natural Disaster Plan, Mississippi is preparing the State Radiological Emergency Response Plan (RERP), the basic response plan for fixed nuclear facility emergencies.

In addition to State plans, Mississippi participates in the Southern Mutual Radiation Assistance Plan (SMRAP) (Southern Emergency Response Council, 1979), which is designed for member States to assist each other in coping with any radiation emergency. The plan includes a list of State contacts and available emergency equipment and instrumentation. Chapter 5 of the plan covers transportation emergencies.

Finally, an integral part of the State radiological planning is the capability to call upon Federal resources during emergencies. If requested by the State, key Federal agencies provide for State and local assistance through the Federal Radiological Emergency Response Plan (FRERP) (Federal Emergency Management Agency, 1984), which is discussed in more detail in Appendix A. In addition, the DOE will prepare an emergency preparedness plan for the Richton Dome Repository Project in accordance with DOE Order 5500.3 (DOE, 1981) which will support State and local plans. See Section 6.2.1.2.4 for additional information.

The evidence indicates that the favorable condition is present.

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

Evaluation. The intent of this condition is to require consideration of site-specific weather conditions that could frequently (several times a year) block access to the site for significant periods of time (several consecutive days) to such an extent that the repository would not meet its annual waste acceptance rate. Such a blockage, to be of concern, would have to occur on the final transportation links from the regional highways and railroads.

For the Richton Dome site, these highway links are I-59 and Mississippi State Highway 15, and the repository access road. The SOU and ICG railroads, and connecting repository railroad, are the connecting rail links. Based on the meteorological data in Section 3.4.3 and observations and informal discussions with local residents during site visits, the likelihood of weather causing significant transportation disruptions is very low. Occasional flooding will not significantly disrupt repository operations.

The evidence indicates that the favorable condition is present.

6.2.1.8.3 Analysis of Potentially Adverse Conditions.

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

Evaluation. In application of this guideline condition, a cost of truck or rail access route greater than $10 million is considered expensive. At the Richton Dome site, the highway access route is estimated to cost approximately $3 million and the rail access route may cost up to $16 million.

The evidence indicates that the potentially adverse condition is present.

(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.

Evaluation. In application of this guideline condition, the presence of other than generally flat terrain and the need to cross rivers or lakes is considered potentially adverse. The terrain at the Richton Dome site is generally flat and no river or lake crossings will be required. There is no potential for landslides or rock slides.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. In application of this guideline condition, needed upgrading of either existing highways or railroads that would cost more than $10 million is considered significant. At the Richton Dome site, upgrading on Mississippi State Highway 15 and possibly Mississippi State Highway 42 will be required at a number of points over these routes between

Laurel and Hattiesburg. However, upgrading costs are estimated at less than $6 million. No significant upgrading of existing railroads is required.

The evidence indicates that the potentially adverse condition is not present.

> (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.

Evaluation. Overall local conditions are not expected to significantly increase transportation costs, environmental impacts, or risks other than stated above.

The evidence indicates that the potentially adverse condition is not present.

6.2.1.8.4 Analysis of Disqualifying Condition. The transportation guideline does not have a disqualifying condition.

6.2.1.8.5 Conclusion for Qualifying Condition. Several feasible highway and railroad access routes to the Richton Dome site have been identified that do not conflict irreconcilably with: a National Park, National Wildlife Refuge, National Wilderness Preserve, National Wild and Scenic River, or National Forest. While the existing abandoned right-of-way, which may be used for repository access, passes through a small portion of De Soto National Forest, the fact that it was acceptable in the past indicates it is not an irreconcilable conflict. These routes can be designed, constructed, and upgraded using available technology, and will not require waste packaging standards more stringent than existing NRC and DOT regulations; nor will development of new packaging containment technology be needed. A preliminary evaluation of operations over these highway and railroad access routes to the Richton Dome site indicates that waste transportation operations can be conducted over these routes without unacceptable risk to the public, or unacceptable environmental impacts. Adequate protection of the public and the environment can be provided during access route construction and operation over these routes.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-7 summarizes the evaluations and findings for the postclosure and preclosure Technical Guidelines not requiring site characterization.

6.2.2 System Guidelines

The DOE Siting Guidelines, 10 CFR Part 960, set forth System Guidelines which specify performance requirements that must be satisfied by a repository. Each System Guideline has an associated set of Technical Guidelines, which define those site conditions which may influence whether a site can satisfy the performance requirements.

In Section 6.2.1, site conditions defined in the Technical Guidelines pertinent to preclosure performance assessment and not requiring site characterization were examined individually. In this section, sets or clusters of site conditions are evaluated in the context of their interactive and integrated contribution to satisfying preclosure System Guideline requirements.

The preclosure System Guidelines (10 CFR 960.5-1) consist of three parts. The first two, Preclosure Radiological Safety (10 CFR 960.5-1[a][1]), and Environment, Socioeconomics, and Transportation (10 CFR 960.5-1[a][2]), are treated in this section (6.2.2) because they involve the Technical Guidelines not requiring site characterization (see Section 6.1 for explanation). The third part of the preclosure System Guidelines is Ease and Cost of Siting, Construction, Operation, and Closure (10 CFR 960.5-1[a][3]. It includes Technical Guidelines that do require site characterization and is addressed in Section 6.3.4.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Site Ownership and Control	960.4-2-8-2	6.2.1.1		
(a) 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.			The Richton Dome site is on privately owned land. No lands owned by the DOE are located in the vicinity of the proposed repository site. The Federal government has the authority to lease, purchase, or condemn privately owned lands under Federal law. It may control access so that surface and subsurface activities will not lead to radionuclide releases greater than those allowable under requirements specified in Section 960.4-1.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Condition.				
Present ownership and control of land and all surface and subsurface rights by the DOE.			The DOE does not presently own or control land and all surface and subsurface rights at the Richton Dome site.	The evidence indicates that a favorable condition is not present.
(c) 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.			The Richton Dome site is located on privately owned land for which the DOE can negotiate purchase-sell agreements. If negotiations for purchase-sell agreements are unsuccessful, the DOE can obtain the necessary ownership rights by condemnation.	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Condition.				
This guideline has no disqualifying condition.				
Population Density and Distribution	960.5-2-1	6.2.1.2		
(a) 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 limit allowable under the requirements specified in Section 960.5-1(a)(1).			Projected radiation doses to which the public may be exposed (even as close as at the Restricted Area site perimeter) are less than 0.07 millirem per year compared to a regulatory limit of 25 millirem per year.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions.				
(1) A low population density in the general region of the site.			Average population density in the region is 40 persons per square mile (national average is 76 per square mile).	The evidence indicates that a favorable condition is present.
(2) Remoteness of the site from high population areas.			The nearest highly populated area is Petal/Hattiesburg (population 49,300), 25 kilometers (16 miles) away.	The evidence indicates that a favorable condition is present.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
(Page 2 of 11)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions.	960.5-2-1	6.2.1.2		
(1) High residential, seasonal, or daytime population density within the projected site boundaries.			There is a low residential and daytime population in the dome area.	The evidence indicates that a potentially adverse condition is not present.
(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.			The town of Richton (population 1,200), with an area of 1 square mile, adjoins the site.	The evidence indicates that a potentially adverse condition is present.
(d) Disqualifying Conditions.				
A site shall be disqualified if-				
(1) Any surface facility of a repository would be in a highly populated area; or			The site is not located in a highly populated area (see b 2 above).	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).
(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			Surface repository facilities will not be located adjacent to the town of Richton.	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).
(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (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 DOE finds no site-specific conditions that would prevent preparation of an emergency preparedness plan.	The evidence does not support a finding that the site is disqualified (Level 1).
Site Ownership and Control	960.5-2-2	6.2.1.3		
(a) 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 operations 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).			Currently, the DOE owns none of the land comprising the Richton Dome site. All land is privately owned. The DOE has the authority, however, to acquire such land as is required for the repository through negotiations for lease or purchase. Should negotiations fail, the DOE is empowered to condemn the contested property.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Condition.				
Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.			The DOE does not presently own or control the land and all surface and subsurface mineral and water rights. All land is privately owned.	The evidence indicates that a favorable condition is not present.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
(Page 3 of 11)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) <u>Potentially Adverse Condition</u>.	950.5-2-2	6.2.1.3		
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.			The DOE is empowered to negotiate the lease, purchase, or transfer of the necessary land rights, to the repository area. In the event that negotiations fail, required ownership rights can be obtained through condemnation proceedings.	The evidence indicates that a potentially adverse condition is not present.
(d) <u>Disqualifying Condition</u>.				
This guideline has no disqualifying condition.				
Meteorology	960.5-2-3	6.2.1.4		
(a) <u>Qualifying Condition</u>				
The site shall be located such that expected meteorological conditions during repository operations 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).			Repository construction will result in radionuclide concentrations of less than 0.06 percent of 10 CFR Part 60 limits for releases to the unrestricted area. Repository operational releases are expected to be less than 5.0 percent of the 10 CFR Part 60 limit. Atmospheric dispersion can be expected to further reduce concentrations. The maximum exposed individual is expected to receive an annual dose of less than 0.66 millirem per year from inhalation, submersion, and ingestion, which is well below regulatory limit of 25 millirems per year.	The evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition (Level 3).
(b) <u>Favorable Condition</u>.				
Prevailing meteorological conditions such that any radioactive releases to the atmosphere during reaspository 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.			Analysis of stability data and wind speeds indicates that prevailing meteorological conditions are expected to provide fair-to-good atmospheric dispersion.	The evidence indicates that a favorable condition is present.
(c) <u>Potentially Adverse Conditions</u>.				
(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.			The prevailing wind direction at Jackson is from the south-southeast; the nearest population center downwind of the site is Laurel, which is approximately 40 kilometers (24 miles) away. Although analysis indicates that radiation exposure will be more than an order of magnitude below allowable limits the presence of Laurel, MS, downwind is sufficient to find a potentially adverse condition.	The evidence indicates that a potentially adverse condition is present.
(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.			Analysis of meteorological data indicates there are approximately 27 to 41 days per year when the potential for hampering repository operations exists. Effects of extreme weather can be mitigated by appropriate facility design and operation procedures.	The evidence indicates that a potentially adverse condition is present.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site (Page 4 of 11)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(d) Disqualifying Condition.	960.5-2-3	6.2.1.4		
This guideline has no disqualifying condicion.				
Offsite Installation and Operations	960.5-2-4	6.2.1.5		
(a) Qualifying Condition.				
The site shall he 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 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).			There is no military or nuclear facility within an 8-kilometer (5-mile) radius of the repository, nor any other facility which would contribute radionuclide emissions. Two highways in the vicinity of the site are considered to be hazardous operations because they may be used to transport explosive or toxic materials. It is unlikely that a transportation incident could affect repository operations.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) 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.			No nuclear operations are located within 8 kilometers (5 miles) of the dome. The nearest nuclear power reactor is at Port Gibson, MS, approximately 210 kilometers (130 miles) away.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions.				
(1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.			Two state highways which pass within 8 kilometers (5 miles) of the proposed surface facility could be used to transport explosive or toxic cargoes. The Tiger and Glazier oil and gas fields also lie within 8 kilometers (5 miles) of the repository site.	The evidence indicates that a potentially adverse condition is present.
(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.			The nearest nuclear reactor is Grand Gulf, located at Port Gibson, Mississippi, approximately 210 kilometers (130 miles) away. Because of this distance, the combined projected and actual releases of radionuclides from the repository and the reactor would not exceed maximum permissible values.	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Condition.				
A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with respository siting, construction, operation, closure, or decommissioning.			There are no atomic energy defense activities in proximity to the site.	The evidence does not support a finding that the site is disqualified (Level 1).

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Environmental Quality	960.5-2-5	6.2.1.6		
(a) 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.			Dedication of substantial acreage will cause a variety of environmental impacts. Impacts can be acceptably mitigated to prevent significant adverse environmental consequences. No adverse impact significant enough to prevent System Guideline 960.5-1(a)(2) from being met has been identified.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) 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.			Because the DOE does not control all procedural aspects of compliance with Federal and Federally mandated State and local requirements, it cannot project that all requirements can be met within time constraints.	The evidence indicates that a favorable condition is not present.
(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.			Satisfaction of this condition requires a finding that such impacts can be mitigated to an insignificant level. All activities can be mitigated to an acceptable level, but not all will be insignificant.	The evidence indicates that a favorable condition is not present.
(c) Potentially Adverse Conditions.				
(1) Projected major conflict with applicable Federal, State, or local environmental requirements.			No major conflicts with any Federal or Federally mandated State environmental requirements are anticipated.	The evidence indicates that a potentially adverse condition is not present.
(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.			There are no identified significant impacts which cannot be avoided or mitigated.	The evidence indicates that a potentially adverse condition is not present.
(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.			The nearest protected lands are part of De Soto National Forest 4.8 kilometers (3 miles) north of the Richton Dome. No significant impacts are projected.	The evidence indicates that a potentially adverse condition is present.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(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.	960.5-2-5	6.2.1.6	The nearest state-protected resource is Paul E. Johnson State Park about 20 miles west of the site. No significant adverse impacts are projected.	The evidence indicates that a potentially adverse condition is not present.
(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.			No significant Native American cultural resources are known to exist in the dome area. Should any significant resources be discovered in surveys prior to site development, mitigation measures (developed in consultation with the SHPO) will be implemented to ensure no adverse impacts will occur.	The evidence indicates that a potentially adverse condition is not present.
(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.			There are no known or designated critical habitats for threatened and endangered species that could be compromised by the repository or its support facilities.	The evidence indicates that a potentially adverse condition is not present.
(d) <u>Disqualifying Conditions</u>.				
Any of the following conditions shall <u>disqualify</u> 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.			<u>Air Quality</u> - Fugitive dust emissions projected for site preparation and construction can be mitigated to levels acceptable to State permitting agencies for similar construction activities. <u>Water Quality</u> - Local and temporary increases in turbidity, salt-pile runoff and surface water runoff can be mitigated or avoided by design and engineering practices. <u>Cultural Resources</u> - No known significant cultural resources will be affected by project activities; mitigation measures would be developed in consultation with SHPO for any resources found during site surveys. <u>Salt Management and Disposal</u> - For the projected volumes of salt to be disposed of, and the rate and length of time of discharge, practical mitigative measures can be implemented so there would be no significant adverse environmental impact. <u>Radiological</u>. A conservative predictive radiological impact analysis indicates that exposures of the public during construction and operation of the repository will be below health and safety requirements established by NRC and EPA.	The evidence does <u>not</u> support a finding that the site is disqualified (Level 1).

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
	960.5-2-5	6.2.1.6	Biota - There are no known threatened or endangered species, or critical or designated habitats present on the site. Should the presence of protected species or habitat be found during a site survey, continued consultation with the Fish and Wildlife Service will determine the extent of impact, if any, and appropriate mitigation measures for protection of endangered species. Land Use - Existing land use and mineral resources are not unique to the area. Compensation can mitigate direct financial impact on owners of affected resources or lands. Development can occur in other parts of Richton and to the south. Noise - Predictive noise level studies indicate that EPA guidelines for sound levels are likely to be met off site, except for temporary and intermittent levels that may affect several residences during site characterization. Visual Aesthetics - Visual impacts from development of a rural landscape and night lighting will be screened from most points of view by the surrounding forest land.	
(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 or the National Wild and Scenic Rivers System.			The site is not located within a component of these protected resources.	The evidence does not support a finding that the site is disqualified (Level I).
(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated use of a component of the National Park System, the National Wildlife Refuge System, the National Wildlife 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.			Based upon the analysis presented in Section 6.2.1.6, the repository restricted area and its support facilities would not conflict irreconcilably with the dedicated use of any Federal- or State-protected resources.	The evidence does not support a finding that the site is disqualified (Level I).
Socioeconomic Impacts	960.5-2-6	6.2.1.7		
(a) Qualifying Conditions.				
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.			The potential demands on surrounding communities can be accommodated by reasonable mitigation measures. The relatively large labor force and population base, along with the economic diversity in the region, are favorable for repository development. Local employment, business sales, and government revenues are projected to increase.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(b) Favorable Conditions.	960.5-2-6	6.2.1.7		
(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.			The projected net change in total population within commuting distance of the site is less than 1 percent of the existing population during the peak repository construction period. Housing capacities within counties receiving project-related in-migrants are projected to be adequate even after these increased housing needs are met.	The evidence indicates that a favorable condition is present.
(2) Availability of an adequate labor force in the affected area.			The local work force is estimated to satisfy 60 percent of the required repository-related work force.	The evidence indicates that a favorable condition is not present.
(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.			There will be employment growth attributed to repository-related activities. Direct local material purchases are estimated to increase the total retail sales. Increases in local sales and property taxes are expected. The ability of local governments to provide improved community services will be determined by local officials and enhanced by grant provisions of the NWPA.	The evidence indicates that a favorable condition is present.
(4) No projected substantial disruption of primary sectors of the economy of the affected area.			The primary sectors of the economy are projected to increase because of increased wages, direct local purchases and sales. The withdrawal of commercial forest lands for repository development will not substantially disrupt the regional forest industry.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions.				
(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.			Because of the favorable conditions listed above, it is not expected that the project will have significant adverse impacts.	The evidence indicates that a potentially adverse condition is not present.
(2) Lack of an adequate labor force in the affected area.			The local work force will satisfy only 60 percent of the projected repository-related work force.	The evidence indicates that a potentially adverse condition is present.
(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.			There is no need to purchase or acquire water rights. Water supply for repository activities is expected to be available from local ground-water resources. No planned development in the study area has been identified which would be affected by water use projected for the repository.	The evidence indicates that a potentially adverse condition is not present.
(4) Potential for major disruptions of primary sectors of the economy of the affected area.			Project is expected to increase the primary sectors of the economy of the affected area.	The evidence indicates that a potentially adverse condition is not present.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(d) <u>Disqualifying Condition</u>.	960.5-2-6	6.2.1.7		
A site is disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite suppliers presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by reasonable measures.			Local ground-water resources are adequate to meet repository needs. Offsite supplies would not be affected. Potential impacts can be mitigated by planned design and engineering features.	The evidence does <u>not</u> support a finding that the site is disqualified (Level 1).
Transportation	960.5-2-7	6.2.1.8		
(a) <u>Qualifying Condition</u>.				
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 resources 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.			Based on preliminary analyses of representative access routes and projected transportation operations, there is no indication that the qualifying condition can not be met.	The evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition (Level 3).
(b) <u>Favorable Conditions</u>.				
(1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:			One of the cited characteristics is present (iv). See also Chapter 7 for comparison with other siting options.	The evidence indicates that a favorable condition is present.
(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.				

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site (Page 10 of 11)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(v) Such routes bypass local cities and towns.	960.5-2-7	6.2.1.8		
(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.			A total of 37 kilometers (23 miles) of local roads must be upgraded.	The evidence indicates that a favorable condition is not present.
(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.			The distance travelled on regional highways between the end of the site access road and I-59 is 35 kilometers (22 miles).	The evidence indicates that a favorable condition is present.
(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.			The number of interchange points ranges from two to four. One is considered favorable.	The evidence indicates that a favorable condition is not 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 wastes, interim storage facilities, and other repositories.			Projected life-cycle costs and risks are the lowest of all the potential sites (see Chapter 7).	The evidence indicates that a favorable condition is present.
(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.			Four Class I railroads serve the region, and two railroads currently serve Laurel. Fifteen motor carriers are authorized to transport hazardous waste in the area.	The evidence indicates that a favorable condition is present.
(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.			State and local ordinances are not expected to impede transportation.	The evidence indicates that a favorable condition is present.
(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.			A State Natural Disaster Plan and State Radiological Emergency Response Plan are in the final stages of preparation.	The evidence indicates that a favorable condition is present.
(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.			Temporary flooding may occur as a result of seasonal storms, but these will not result in significant disruptions.	The evidence indicates that a favorable condition is present.
(c) <u>Potentially Adverse Conditions</u>.				
(1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.			Access route construction is estimated to cost $3 million for highway and $16 million for rail.	The evidence indicates that a potentially adverse condition is present.

Table 6-7. Preclosure and Postclosure Technical Guidelines Not Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switch-backs, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.	960.5-2-7	6.2.1.8	No unusual terrain features exist that would complicate construction or operations.	The evidence indicates that a potentially adverse condition is not present.
(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.			Mississippi State Highways 15 and 42 may have to be upgraded at a number of points at a cost of $6 million.	The evidence indicates that a potentially adverse condition is not present.
(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.			Overall local conditions are not expected to create significant adverse impacts (see comparison in Chapter 7).	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Condition				
This guideline has no disqualifying condition.				

6.2.2.1 Preclosure Radiological Safety

For the Preclosure Radiological Safety Guideline (10 CFR 960.5-1[a][1]), the pertinent system elements are (1) the site 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 workers of the repository from radiological exposures.

Although guidelines specify compliance with regulations "during repository operation and closure," the operational phase is interpreted broadly in this analysis to include all periods during which radioactive emissions might occur, that is, during construction and operation.

6.2.2.1.1 System Guideline Requirements. The requirements for preclosure radiological safety are defined in Part (1) of 10 CFR 960.5-1(a) as follows:

> 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.

The specific requirements of these regulations are detailed in Section 6.4.1, where they are used for comparison with results of radiological analysis of the Richton Dome site.

Evaluation Process. Those system elements pertinent to achieving compliance with System Guideline requirements are evaluated as a total integrated system. The evaluation focuses principally upon the potential exposure of the public. Estimated exposure levels are compared with regulations established for protection of health and safety. In calculating potential dose to the public, a generic repository design of the type likely to be constructed, such as that described in Chapter 5, was evaluated to establish the inventory of radionuclides that might be released during construction and operation. For construction, this consisted largely of naturally occurring radioactive radon and related decay products released from entrapment in the mined material. For normal operations, radon from mining and a small inventory of radionuclides postulated to result from leakage from damaged spent fuel elements were assessed to be the source term (airborne effluents). To estimate concentration levels at the point of release to the atmosphere, these source terms were assumed to be diluted by ventilation air exhaust and to be released to the atmosphere via a stack.

Based upon a restricted area of approximately 165 hectares (407 acres) a distance to the restricted area boundary of 240 meters (800 feet) was estimated. For normal operations, exposure levels to an individual assumed to be continually present at the boundary were calculated for all potential exposure pathways - inhalation, submersion, and ingestion. Meteorological dispersion of the stack-released concentrations was based upon estimated meteorological conditions (Stability Class D and 3-meter per second [6.6 mile-per-hour] winds) as derived from Jackson, Mississippi, data (see Section 3.4.3).

Potential exposures of the public surrounding the site were estimated using source terms and meteorology, described above, together with demographic data showing population distributions in relation to wind directions and distances from the site boundary.

Accidental events which might cause releases of radionuclides from the repository were postulated. These were developed through analysis of expected waste handling operations in the handling/packaging facility and the mine. The consequences of exposures to an individual assumed to be continuously at the restricted area boundary, and to the public surrounding the site, were evaluated.

The work force radiological exposure in the subsurface will be determined by the amount of radon released during the mining operations and the radiation shielding provided for protection from the waste packages. Work force radiological environment in the surface facilities will be determined by shielding of waste packages, shielding incorporated into the building structures, use of remote handling systems, ventilation controls, and other practices common to radiological protection in the workplace. Site-specific designs will reflect these considerations to assure compliance with radiological health and safety requirements in these restricted areas. Existing mining of salt and uranium and the operation of many nuclear facilities wherein high-level wastes are handled, stored, or processed attest to the availability of technology to provide for worker protection.

Since a demonstration of compliance with radiological health and safety requirements for the worker is a facility design requirement and not a factor influencing determination of site suitability, analysis of potential radiation exposures to workers on site is deferred until site-specific designs are developed.

Relevant Data. Descriptive information on system elements pertaining to this System Guideline can be found in the following sections:

- Demography (Section 3.6.1)
- Meteorology (Section 3.4.3)
- Site Boundaries (Section 3.4.1)
- Offsite Installations (Section 3.5)
- Facility Design (Section 5.1)
- Source Terms (Section 6.4.1).

Data Assumptions and Uncertainties. Results of this analysis should be viewed in the context of assumptions and uncertainties set forth below. Additional detailed assumptions are described in Waite et al. (1985, BMI/ONWI-541). The effect of these conservative assumptions is to predict what is believed to represent an upper bound for radiological exposures during the preclosure period. Principal assumptions are as follows for each of the following topics.

Source Terms. Source terms (radioactive emissions) have been estimated for a generic facility design. The radionuclides anticipated to be released during construction, before waste arrives, consist of naturally occurring radon and its decay products. Releases during normal operations are attributed to damage of the cladding of spent fuel pins during disassembly of spent fuel assemblies. Naturally occurring radionuclides were assumed to be released from ground level; operation releases were assumed to occur from an elevated stack.

Accident analysis was based upon accident scenarios developed in conjunction with the preparation of the final environmental impact statement for the high-level waste repository program (DOE, 1980, DOE/EIS-0046F; Yook et al., 1984, BMI/ONWI-551).

Meteorology. Meteorological dispersion parameters for assessing offsite radiation levels from normal operations were derived from Jackson data. Because the terrain is similar, these data are believed to be reasonably representative of what is likely to occur at the site. For the accident scenarios, very poor meteorological conditions (F-class Stability and 1 meter per second [2.2 miles per hour] wind speed) independent of the site were conservatively assumed. Consistent with NRC guidance, annual average meteorological conditions have been used in establishing the appropriate atmospheric stability classifications for normal conditions.

Demography. Demographic distribution of data is based upon 1980 census information. Such data are regionally accurate, but do not provide the detail for depicting the near-site setting.

6.2.2.1.2 Analysis. Analysis of the potential radiological impacts of preclosure repository activities at the Richton Dome site is presented in Section 6.4.1. The results of this systems analysis, based upon evaluation of the site against the requirements of System and associated Technical Guidelines, are presented at the end of Section 6.2.2.

Site-specific characteristics pertinent to preclosure radiological safety are generally favorable. An exception to this is meteorology, presently assumed to be similar to Jackson, which could be poor at times (i.e., occasional stagnant conditions). From an integrated system viewpoint, meteorological dispersion conditions that could be poor at times are not likely to prevent compliance with the radiation protection requirements. Radioactive releases from a repository are predicted to be very small and are expected to more than compensate for the less than favorable meteorological dispersion conditions. Modeling results (Section 6.4.1) 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, or greater than 0.66 millirem in any year from normal operations during the operational period. Comparing these values with 40 CFR Part 191 limits of 25 millirems per year whole-body or approximately 10 millirems per year from natural background, it appears that a repository can be located and operated at the Richton Dome site with insignificant radiological exposure risks to the public.

6.2.2.1.3 Conclusion for Qualifying Condition. Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.2.2.2 Environment, Socioeconomics, and Transportation

Ranked second in importance in the preclosure System Guidelines is the guideline dealing with environment, socioeconomics, and transportation (960.5-1(a)(2)). The pertinent system elements 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.

6.2.2.2.1 System Guideline Requirements. Part (2) of the preclosure System Guideline 960.5-1(a) defines the requirements for environment, socioeconomics, and transportation as follows:

> 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. The type and nature of activities anticipated during repository siting, construction, operation, and decommissioning were examined for potential effects on the quality of the environment and the socioeconomic welfare of communities that might be most affected. Such activities included those required to emplace the facility at the site and to provide transportation and utility corridors.

Environmental implications of these activities were examined with respect to the projected ability to comply with applicable Federal and State statutes including land use, air quality, water quality, ecological resources, noise, historic and cultural resources, and radiological protection.

Radiological hazards due only to transportation of wastes are evaluated under this System Guideline. Radiological hazards from construction, operation, and decommissioning of the repository were considered under the preclosure Radiological Safety Guideline, discussed in Section 6.2.2.1.

In addition, the effects that physical and human resources needed for project development might have on social and economic characteristics of potentially impacted communities were examined. This included estimates of work-force requirements, direct and indirect in-migration, and commensurate needs for expanded community services and facilities.

Areas of potentially significant impact were then identified and the potential for implementing measures to mitigate those impacts was assessed.

Relevant Data. Descriptive material pertaining to this System Guideline can be found in sections as follows:

- Environment (Sections 3.2, 3.3, 3.4, 4.2.1, 5.2, 5.3.2)
- Socioeconomics (Sections 3.6, 4.2.2, 5.4, 6.2.1.7)
- Transportation (Sections 3.5, 4.2.1.10, 5.3.1, 6.2.1.8).

Assumptions and Data Uncertainty. The assumptions and uncertainties associated with this System Guideline analysis are reflected in the Assumption and Data Uncertainties section of each of the Technical Guidelines that make up the System Guideline (Environmental Quality, Socioeconomics, Transportation). The assumptions particularly pertinent to this System Guideline analysis include the following:

1. Impacts of actual repository access routes will be similar to those calculated for the alternative routes.

2. Projections of water availability for repository operations are reasonable.

3. Site-specific surveys will confirm that no threatened or endangered species or significant cultural resources will be significantly impacted.

4. In-migration of repository workers will be similar to actual in-migration at other large-scale energy projects.

5. Existing shaft sealing technology is sufficient to provide protection of the overlying aquifers.

6. Offsite disposal of salt is a viable option; salt encrustation provides the predicted stabilization of the onsite storage pile.

7. Fugitive dust emission factors based on limited offsite measurements, where soil characteristics such as silt and moisture content are different from those existing at the site, are suitable for modeling TSP impacts.

8. Sound emission levels are accurate to $\pm$ 5 dB. Unfavorable wind and temperature gradient effects, which would increase noise propagation toward a sensitive receptor such as a residence, would be an infrequent occurrence.

6.2.2.2.3 Analysis. Impacts of repository-related activities at the Richton Dome site with respect to the environment, socioeconomics, and transportation were analyzed in Chapters 4 and 5. Site conditions were compared with the Technical Guidelines (Sections 6.2.1.6, 6.2.1.7, and 6.2.1.8).

These analyses showed that the site conditions are such that the substantial Federal and Federally mandated State land, air, water, and natural resources environmental protection requirements are likely to be met but not necessarily within time constraints.

Environmental concerns addressed in the impact assessments (Chapters 4 and 5) included consideration of the effects of repository and related transportation/utility corridor development and operations on:

- Air quality
- Existing noise levels
- Water quality/availability
- Cultural resources
- Land use
- Biota
- Visual aesthetics.

Assessments also address social and economic impacts to communities resulting from population in-migration into a rural area. These impacts relate primarily to expanded service and facility requirements needed for increased populations, the costs of providing these infrastructure needs, and the potential social changes that might result.

The principal results of these environmental and socioeconomic impact assessments are summarized in Table 6-8. Particularly noteworthy are the following:

Air Quality. The DOE believes that residual air quality impacts are acceptable because they are less than secondary standards.

Noise. Clearing and construction activities will cause an increase in 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.

Water Quality. Construction of shafts to the underground facility will require 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.

Increased sediment discharge and turbidity may occur but will be temporary and localized in nature; therefore, the impacts to surface water quality will be minimal.

Temporary surface storage of mined salt poses the need to minimize dissolution during the storage period and prevent both surface runoff and penetration to ground water. Practical engineering measures will mitigate impacts from salt storage.

Cultural Resources. No known cultural resources will be affected by project activities. Mitigation measures would be developed in consultation with the Mississippi State Historic Preservation Officer for any resources found during site surveys.

Land Use. The residual impacts on land use will be acceptable because much of the forested land has been cleared or recently seeded and is not unique to the area and because areas suitable for development remain available in Richton and to the south and the DOE will mitigate the impacts of moving residents.

The site will 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.

Only 2.3 percent of the Richton Dome is classified as prime farmland. Soil protection measures will be taken to minimize impacts.

Salt handling and control measures will be used to minimize the deposition of wind-blown salt in adjacent lands. Insignificant effects on forest and crop productivity are anticipated due to the small area to be impacted from the salt pile and the minor levels of salinity buildup in the soil, which can be accommodated without having adverse impacts on crop and tree growth.

There should be no transportation access or access impacts on airspace with the Camp Shelby military operation area.

Biota. The existing data base indicates that no unique aquatic or terrestrial species are likely to be significantly affected.

Visual Aesthetics. 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. Sensitivity to the visual intrusion potential of the facilities will be reflected in the design.

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Richton Dome Site

System Guideline	Associated Technical Guidelines	Assessment Results	Findings
Preclosure Radiation Safety. Qualifying Condition: System Guideline 960.5-1(1) defines the requirements for preclosure radiological safety as follows: "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."	Population Density & Distribution 960.5-2-1 Site Ownership & Control 960.5-2-2 Meteorology 960.5-2-3 Offsite Installations 960.5-2-4	System Guideline: Modeling results (Section 6.4.1) indicate that upper bounds exposure to any member of the public is estimated to be less than 0.07 mrem, whole body per year from all exposure pathways (inhalation, immersion, ingestion). This exposure is estimated to occur during the construction period due to release of naturally occurring radionuclides. This estimated exposure level is well below the regulatory limit of 25 mrem per year. Exposures during other preclosure periods will be even less.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
	Population Density & Distribution (Section 6.2.1.2)	Technical Guidelines: No highly populated areas are present in the immediate vicinity of the site. The nearest highly populated area is Petal/Hattiesburg (population 49,300), located 25 kilometers (16 miles) from the site. The town of Richton (population 1,200) is located 1.6 kilometer (1 mile) from the restricted area. The average population density in the region is 40 persons per square mile, below the national average of 76.	
	Site Ownership and Control (Section 6.2.1.3)	Land overlying the Richton Dome is privately owned. Government land acquisition is not precluded. Approximately 160 hectares (400 acres) of surface area would be subjected to restricted access. Distance from the mine ventilation exhausts to the restricted area boundary of at least 240 meters (720 feet) will be available. Surface lands may be available for public use if not in restricted area.	

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Richton Dome Site
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System Guideline	Associated Technical Guidelines	Assessment Results	Findings
	Meteorology (Section 6.2.1.4)	Based upon analyses of several years of regional meteorological data, it is projected that wind conditions in the vicinity of the site will provide fair-to-good atmospheric dispersion. The prevailing winds in the region are generally away from local human settlements. The potential for severe weather that could hamper repository operations is estimated to occur 39 to 45 days per year. This relates primarily to days of dense fog and is not considered to be a disqualifying situation.	
	Offsite Installations (Section 6.2.1.5)	No military or nuclear installations are located near enough to the site to interfere with repository operations or to contribute emissions to those from the site. The nearest nuclear facility is a reactor under construction 210 kilometers (130 miles) distant. The restricted airspace of the De Soto military operations area extends over part of the dome.	
960.5-1(a)(2) Environment, Socioeconomics, Transportation. System Guideline 960.5-1(a)(2) defines the requirements for environment, socioeconomic, and transportation as follows: "During repository siting, construction, operation, closure, and decommissioning, the public and the environment shall be protected from the hazards posed by the disposal of radioactive waste."	Environmental Quality 960.5-2-5 Socioeconomic Impacts 960.5-2-6 Transportation 960.5-2-7	System Guideline: Analysis (Section 6.2.2.2.3) shows a variety of localized impacts will be experienced. These include (1) increase in the noise levels and fugitive dust, mostly during site clearing and repository construction; (2) localized traffic flow changes and temporary travel inconvenience during road upgrades. No impacts were identified that would not be controllable or reduced to generally acceptable conditions by mitigating measures. Some in-migration of workers can be expected with	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Richton Dome Site

System Guideline	Associated Technical Guidelines	Assessment Results	Findings
		attendant needs for community facilities and support services. Communities within commuting distances are likely to be able to provide infrastructure without undue stress. Exceptions, if encountered, can be relieved by mitigating measures. Increased payroll and stimulated sales should enhance the economy of the affected areas.	
	Environmental Quality (Section 6.2.1.6)	Technical Guidelines: Assessments of what is known about the site and surrounding area and the potential impact of preclosure repository activities provide a reasonable basis for confidence that requirements for the protection of the health and welfare of the public and the quality of the environment can be achieved at the Richton Dome site. This conclusion should be viewed within the context of assumptions and data uncertainties presented in Section 6.2.1.6. Repository construction and operation activities will result in releases off site of very small amounts of radioactivity, mostly from disturbing radon entrapped in the mined formations. As a result, analyses (Section 6.4.1) indicate that radiological health and safety requirements can be met at the restricted area boundary with considerable margins. The dedication of substantial acreage, both surface and subsurface, to repository use will cause a variety of environmental impacts. No impacts have been identified that cannot be mitigated to acceptable levels.	

Table 6-8. Preclosure System Guidelines Not Requiring Site Characterization, Richton Dome Site
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System Guideline	Associated Technical Guidelines	Assessment Results	Findings
960.5-1(a)(2) Environment, Socioeconomics, Transportation	Socioeconomic Impacts (Section 6.2.1.7)	The only potentially adverse condition identified is a projected inadequacy of a locally available labor supply for all aspects of repository development. Projected impacts to socioeconomic sectors could result from needs for services imposed on local communities from in-migration of workers. The amount of in-migration can be reduced by local job training. Such secondary impacts of in-migration as may be experienced are reducible by mitigation measures, if required.	
	Transportation (Section 6.2.1.8)	Representative corridor studies indicate that access roads from existing highways and railroads to the site are possible to construct without conflict with Federal dedicated lands (960.5-2-5(d)(2) and (3)), and with available technology both for the roads and transport components. Transportation risks are predominantly nonradiological. The site is located in proximity to regional highways and mainline railroads that provide access to the national transportation system. However, some sections of local highways will require upgrading to be adequate for repository use. The potentially adverse condition identified relates to the cost of providing rail access to the site. However, this is a cost issue and does not relate directly to safety or environmental considerations.	

Socioeconomics. Employment predicitions indicate that the available labor supply within communting distances to the site will not be sufficient to satisfy project labor requirements, particularly during peak employment periods. The result is that some in-migration will occur. Job training programs can provide opportunities for employment of area residents, thus decreasing worker in-migration. Indications are that the area can absorb the projected populations chage without significant disruption to 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 will require expanded community services and facilities and may result in social changes in the town of Richton. Advanced community development planning can lessen these impacts.

Transportation. 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.

Radiological risks due to transportation of waste appear to be small. Estimates indicate that the maximally exposed individual could receive up to 5 percent of the normal background radiation.

Potential exists to provide needed new highway and rail routes without disruption to local cities and towns.

6.2.2.2.4 Conclusion for Qualifying Condition. The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-8 summarizes system guidelines discussed in this section.

6.2.3 Conclusions Regarding Suitability of the Site for Development as a Repository Under Guidelines Not Requiring Site Characterization

On the basis of the findings stated in the above discussion of individual guidelines not requiring site characterization and made in accordance with Appendix III of the siting guideline, it is concluded that the evidence does not support a finding that the site is disqualified, and does not support a finding that the site is not likely to meet the qualifying conditions. Therefore, it is concluded that there is no reason to believe that the site is not suitable for site characterization for selection of the first repository site.

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

The purpose of this section is to meet the requirements of Section 112(b)(1)(E)(i) of the NWPA by evaluating the site against those guidelines that require site characterization.

From the 10 CFR Part 960 definition of site characterization, the factors or information needs requiring site characterization have been specified. The corresponding Technical Guidelines that address these factors are as follows:

- Postclosure Technical Guidelines
  - 10 CFR 960.4-2-1 Geohydrology
  - 10 CFR 960.4-2-2 Geochemistry
  - 10 CFR 960.4-2-3 Rock Characteristics
  - 10 CFR 960.4-2-4 Climatic Changes
  - 10 CFR 960.4-2-5 Erosion
  - 10 CFR 960.4-2-6 Dissolution
  - 10 CFR 960.4-2-7 Tectonics
  - 10 CFR 960.4-2-8 and 960.4-2-8-1 Human Interference and Natural Resources

- Preclosure Technical Guidelines
  - 10 CFR 960.5-2-8 Surface Characteristics

- 10 CFR 960.5-2-9 Rock Characteristics
- 10 CFR 960.5-2-10 Hydrology
- 10 CFR 960.5-2-11 Tectonics.

The evaluations of the postclosure Technical Guidelines are addressed in Section 6.3.1. The preclosure Technical Guidelines are evaluated in Section 6.3.3. Application of these Technical Guidelines uses currently available information and assumptions inferred from the technical data base. Compliance of the site with the intent of these guidelines can only be determined adequately with site characterization.

Section 6.3.2 evaluates the Richton Dome site with regard to the postclosure System Guideline. The System Guideline allows comparative evaluations of sites in terms of the capabilities of the natural barriers for waste isolation and to identify innate deficiencies that could jeopardize compliance with existing regulations and standards.

6.3.1 Postclosure Technical Guidelines 10 CFR 960.4-2

The guidelines in this section specify factors to be considered in evaluating and comparing sites on the basis of expected repository performance. They refer specifically to those characteristics and processes at or near the site that will affect the expected performance of the repository. The postclosure Technical Guidelines, the evaluations of the site with regard to them, and the findings with respect to them are summarized in Table 6-11 at the end of Section 6.3.1.8.5.

6.3.1.1 Geohydrology, Guideline 10 CFR Part 960.4-2-1

The geohydrology Technical Guideline is focused on the past, present, and future characteristics of the geohydrologic setting of a site and their potential effects on the waste-isolation capability of a site. The most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. For this reason, the geohydrologic conditions at a site must be thoroughly evaluated using available geohydrological data. The potential effects of future changes on geohydrology need to be analyzed.

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

6.3.1.1.1 Statement of 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.

Evaluation Process. Compliance with the requirements referenced in the qualifying condition is addressed by performance assessment analyses described in Sections 6.4.2.3.5 and 6.4.2.4. The geohydrologic system is evaluated for compatibility with waste isolation, especially pre-waste-emplacement ground-water travel time from the repository to the accessible environment. Further evaluations address the confidence with which existing hydrologic conditions can be modeled and the potential for expected changes in the present hydrologic system.

The modeling used for evaluation of the site for compliance with this qualifying condition is based on data obtained from (1) review of the literature, (2) analysis of water well and sulphur and petroleum exploration well records, and (3) laboratory testing conducted for the Office of Civilian Radioactive Waste Management exploration program. These data are used to describe the ground-water flow systems and the rock parameters, namely, premeability, primary effective porosity, and formation fluid pressures in order to determine the paths, amounts, and times for ground-water travel and associated uncertainty. The evaluations and findings are summarized in Table 6-11 at the end of Section 6.3.1.

Relevant Data. Regional descriptions of the geologic and geohydrologic settings where Richton Dome is located are presented in Chapter 3. Discussions relevant to this guideline include the following:

- Climatology (Section 3.2.2.3)
- Stratigraphy (Section 3.2.3)
- Structure (Section 3.2.5)
- Hydrology, with lithologic descriptions of geohydrologic units and hydraulic head analyses (3.3.2.1)
- Ground-Water Modeling (3.3.2.2)
- Ground-Water Quality (3.3.2.3)
- Disturbed Zone (6.4.2).
- Anomalous Zones (3.2.3.2.4 and 3.2.6.1.2).

No data are available which indicate the potential for movement of ground water through the Richton Dome salt stock. No studies or data document significant fluid occurrence or movement in the interior of salt domes. Information from mines in salt domes and analysis of core samples from domal salt indicate very limited occurrence of fluids (Bradshaw et al., 1968; Knauth and Martinez, 1980; Kupfer, 1980; Roedder and Belkin, 1980, ONWI-212; Jenks and Claiborne, 1981, ORNL-5818; Knauth and Kumar, 1981; Knauth, 1982; Bateman, 1985). Water encountered in mines in domal salt can be grouped into two categories: internal (nonmeteoric or formation) and external (meteoric) water. Internal water reservoirs are generally isolated and are not connected internally with each other or externally to other sources of water. They are of limited size and are often associated with anomalous conditions in the salt deposits (Bateman, 1985). There are no data that document the occurrence of anomalous zones in the Richton Dome salt stock. The potential for the occurrence of anomalous zones in the Richton Dome salt stock are discussed in Section 3.2.3. The potential for any anomalous zone, if indeed such exists, to be a pathway for fluid movement is uncertain. Studies of water leakage in Gulf Coast salt dome mines by Louisiana State University (Kumar and Martinez, 1981) show that the number of reported inflows to domal salt mines from external water sources is small compared to internal water sources, but the inflow rates are generally orders of magnitude higher. However, documented inflows of external water have been related to mining activities and were not associated with naturally occurring fluid pathways through the salt. Indications are that anomalous zones tend to be hydrologically isolated. Reported causes of inflows from external water sources include shaft seal failures or shaft maintenance activities, mining-induced deformation, inadvertent mining too close to the salt stock boundary, and the existence of open boreholes connected to an external water source (Bateman, 1985). Thus, available information suggests there is little fluid to move past a repository in the interior of a salt dome. Fluid that does occur is not in hydraulic communication with ground-water systems outside the dome and therefore could not be driven by any hydraulic gradient to move either laterally or vertically. Most fluid found in domal salt mines has isotopic signatures and characteristics of old or isolated formation water.

Assumptions and Data Uncertainty. A principal assumption is that the geohydrologic system, as it is described in the sections cited under relevant data, is reflective of the natural system. The uncertainty associated with hydrologic parameters used in the following evaluation is described in Section 6.4.2.3.5. A stochastic ground-water flow model (Section 6.4.2.3.5) is used to predict ground-water travel time and is one that particularly addresses the uncertainty associated with the existing data.

Salt permeability is a function of the permeating fluid, confining pressure, and the type and amount of impurities found in the salt deposits. With different permeants and confining pressures, the range of salt permeability has been observed to be from 10^{-22} to 10^{-12} square meter (10^{-7} to 10^{-3} millidarcy) (Bateman, 1985). The higher range of salt permeabilities was derived from tests using permeants such as nitrogen, air mixtures, freon, gasoline, and diesel oil. Brine is the natural permeant of concern for a salt repository assessment, and for which zero to very low permeabilities have been reported. The low permeabilities of brine through salt are due to salt recrystallization and redeposition of impurities (Aufricht and Howard, 1961, p. 736). The containment of brine pockets provides the indirect evidence that in situ rock salts are almost impermeable (Baar, 1977). These internal water reservoirs are hydraulically isolated (MSHA Storage Task Force, 1978; Knauth, 1982).

In general, the laboratory-measured permeabilities are also higher than the in situ permeability measurements. Laboratory specimens generally are disturbed and may exhibit stress-release fractures (Gloyna and Reynolds, 1961, p. 3921). In situ permeability tests may not always reflect undisturbed in situ conditions because of the influence of disturbances by drilling or mining activities. In drill holes and mines, the stress-release fractures and salt creep resulting from in situ stress conditions may cause overestimation of the permeability of the undisturbed salt by many orders of magnitude (Batemen, 1985, p. 19). Some of the higher in situ permeability measurements, when compared to the laboratory data, may result from localized effects or inclusions of anhydrite and shale layers in long test intervals (Tien et at., 1983; Stormont, 1984, SAND84-1057). Recent salt permeability tests show lower permeability values than older tests (Sutherland and Cave, 1978; Blankenship and Stickney, 1983, ONWI-190[3]) due to improvements in test sample collection, handling and testing techniques, and higher sensitivity of test instruments.

The salt permeability range of $10^{-7}$to 10^{-2} millidarcy are used in the analysis of ground-water travel time estimates. This range covers the maximum observed values under in situ confining pressures and brine as a fluid permeant. To address the effect of the uncertainty in salt hydraulic properties (in particular permeability and porosity) on the performance of the geohydrologic system, a range of values has been used in evaluating travel times within the dome (Section 6.4.2.3.5).

Because of the extremely small amount of brine flow in salt, it is difficult to identify the dominant mechanism for ground-water movement through the salt. The guidelines require an estimate of fluid travel time from the repository to the accessible environment. Therefore, a mechanism of fluid movement must be evaluated. Flow by diffusion or brine migration results in travel times to the salt stock boundary of million of years. If interconnected porosity were to exist in domal salt, fluid movement could be calculated assuming Darcian flow parameters. Such an analysis would provide a conservative bound on travel times within salt domes as hypothetical porous media flow rates would greatly exceed potential transport by diffusion unless the permeability is negligible.

To address the requirements of the guidelines on the pre-waste emplacement ground-water travel time from the repository to the accessible environment, a conservative assumption is made that the salt is a porous medium. The uncertainties in hydrogeologic parameters (salt permeability, porosity, and horizontal and vertical hydraulic gradient) are accounted for by considering a range of values based on observed, computed, and reported information about each parameter.

Some uncertainty exists about the nature of the interface of the salt with surrounding sedimentary units and the direction and rate of fluid movement near this interface. Upward flow along the flanks of salt stocks has been suggested to explain the geochemical nature of some caprocks (Walker, 1974, p. 194). At Richton Dome, caprock is known to extend some distance down the flanks of the dome in two wells (Section 3.2.3.2.3) and may provide a barrier to fluid exchange between the salt and surrounding units. Interpretation of geophysical logs from a limited number of wells adjacent to and within the dome flank suggests that the vertical hydraulic conductivities of the Vicksburg-Jackson, Upper Claiborne and Lower Claiborne units are lower near the dome flank than elsewhere in the dome vicinity (Section 3.3.2.1). Because there are no data at this time to suggest vertical flow (upward or downward) along the interface at Richton Dome, assumed travel paths outside the salt stock are based on the regional modeling results.

Uncertainties exist about the choice of specific parameter values, such as vertical and horizontal hydraulic conductivities, for geohydrologic units surrounding Richton Dome. To develop conceptual models, it is assumed that hydraulic properties of the geohydrologic units can be averaged over a regional scale. To assess effective porosity of the sediments surrounding Richton Dome, certain judgments were made. Effective porosities of sediments surrounding the dome were estimated to range from 0.1 to 0.3 based on lithologic descriptions and sidewall core tests (Section 3.3.2.1). Section 6.4.2 discusses these uncertainties and presents the selected parameter values used for modeling. Additional discussion of available data and uncertainties for the geologic setting of Richton Dome, as they relate to hydrologic modeling, is presented in ETC (1984, BMI/ONWI-511; 1985a).

Analysis. The brine that normally occurs within salt deposits is in the form of intracrystalline inclusions, intergranular fluid, and fluid associated with inpurity impurities and chemically bound water. Migration of these different forms of fluids may be driven by various mechanisms. The intracrystalline inclusions tend to migrate under the influence of temperature gradients; the intergranular and interbed fluids tend to move in response to pressure and stress gradients (Jenks and Claiborne, 1981, ORNL-5818; Olander, 1982). The temperatures in a salt repository are not expected to reach levels high enough to mobilize chemically bound water (Shefelbine, SAND82-0152, 1982).

As long as the radioactive waste is significantly hotter than the ambient salt, the intracrystalline inclusions will tend to migrate towards the waste package under the influence of the temperature gradient. The brine accumulating around the package wall will contribute to the degradation of the waste package wall. If the package fails, radionuclide release rates will be controlled by radionuclide solubilities. When the radioactive waste has cooled to near the ambient salt temperature, any brine remaining around the waste package which has not been consumed in reactions with package materials will migrate away from the package by a diffusion-like mechanism. Calculations have been made using a diffusion-like mechanism to transport radionuclides to give estimates of the distance moved within various time frames. It is predicted that the standards for radionuclide release as given in 40 CFR Part 191, which must be met at 10,000 years at a maximum distance to the accessible environment of 5 kilometers (3 miles) are met within a few meters (feet) of the waste package. With this process, radionuclides would take millions of years to migrate to the edge of the salt stock (accessible environment).

A conceptual model for fluid flow within domal salt has been developed assuming Darcian conditions (Section 6.4.2.3.5). The values for permeability were considered to range from 10^{-2} to 10^{-7} millidarcy. The maximum value of this range corresponds to the maximum value of the permeability obtained in laboratory tests conducted at in-situ confining pressure where brine was used as the permeant, as well as the maximum observed value from in situ tests. Gradient was derived from regional modeling studies (INTERA, 1984, ONWI-502). There are no experimental data to indicate that hydraulic gradients exist within undisturbed domal salt. Travel time values derived from these calculations are provided only to demonstrate that fluid travel times within salt stocks greatly exceed regulatory requirements.

Calculations have been made to evaluate the sensitivity of the ground-water system model results to uncertainties in parameter values and to assumptions required to form the model (Section 6.4.2.3.5). Results of such calculations appear in Ertec (1983, ONWI-456, pp. 78-85) and INTERA (1984, ONWI-502 pp. 120-138).

Analyses of existing data were made to evaluate the ground-water flow paths and travel times within the salt stock. Ground-water flow within the host rock is presented in Section 6.4.2.3.5. Although no site-specific data exist to assess the movement of ground water through the Richton Dome salt stock, the poor water-transmitting properties of salt are described. Estimates have been made of possible hydraulic conductivity in salt and possible hydraulic gradients across the salt. Based on an assumption of Darcian flow, these estimates can provide conservative assessments of ground-water travel times through salt.

6.3.1.1.2 Analysis of Favorable Conditions.

(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.

Evaluation. The edge of the salt stock is defined as the boundary of the accessible environment. Current repository design bases have a perimeter pillar of 244 meters (800 feet) of nondisturbed salt. Considering the uncertainty in salt hydrologic properties, a range of possible travel times through the undisturbed (224 meter [800 foot]) buffer zone has been generated (Section 6.4.2.3.5). These analyses are based on the assumption that Darcian flow conditions exist within the salt stock. Based on 1,000 realizations of the input variables (permeability, porosity, hydraulic gradient), the calculated median and mean travel times are 3.5×10^7 years and 2.1×10^8 years, respectively. No travel times under 10,000 years were observed. All values are well in excess of the guideline specification of 10,000 years.

The stochastic approach taken in Section 6.4.2.3.5 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 extreme upper and lower portions of the travel-time distribution are characteristic of travel times along unlikely paths of radionuclide travel, and therefore inappropriate for evaluating this favorable condition. The DOE considers this judgement to be consistent with the NRC staff position regarding the ground-water travel-time requirement in 10 CFR Part 60 (Browning, 1985).

The database resulting from site characterization will permit better parameter estimation with less uncertainty and a more realistic construction of the travel-time model. These improvements are expected to narrow the range of travel times.

For the interim, a measure of central value of the travel-time distribution is considered appropriate for evaluating the proposed site against the favorable condition. The mean is a mathematical approximation of the expected travel time (Davenport, 1970). The median is also a measure of central value and, in this case, a more conservative value. For this reason, median travel time values, as well as mean values, are used in evaluating this favorable condition. In each set of conservative calculations of ground-water travel time (Section 6.4.2.3.5), both 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 evidence indicates that the favorable condition is present.

(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.

Evaluation. Geologic evidence from the site and the surrounding region indicates that the hydrologic processes operating during the Quaternary Period are similar to those operating now. Variations that have occurred in response to the Quaternary climate cycles and the associated sea level fluctuations (Section 6.3.1.4) involve slight increases and decreases in precipitation, hydraulic gradients, and rates of ground-water movement.

The ability of the site to isolate wastes is related chiefly to the very low permeability of the host salt and the resulting long travel times to the accessible environment. Conservatively high rates of fluid movement through the salt have been calculated (Section 6.4.2.3) based on assumed Darcian flow conditions. At these calculated rates, considerably more than 100,000 years would be required for fluid movement horizontally from a repository to the margin of the salt. This estimate would not be changed significantly by the relatively small climate fluctuations that would be expected over the next 100,000 years.

Therefore, it is concluded that hydrologic processes operating during the Quaternary would not, if continued into the future, affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

The evidence indicates that the favorable condition is present.

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

Evaluation. The stratigraphic, structural, and hydrologic features of the region are discussed in detail in Sections 3.2 and 3.3. The following conclusions have been developed from this discussion. The stratigraphy of the region is relatively simple and consists of recognizable and laterally continuous strata. Faults and, to a limited extent, folds do exist, but they tend to show little expression within the units considered for detailed geohydrologic study and, therefore, have little if any effect on ground-water flow. The structural complexity around the dome flanks is somewhat uncertain; hence the potential for significant upward or downward flow along the flanks is uncertain. Modeling of dome flanks is standard practice within the oil industry and modeling of deep circulation systems caused by zones of enhanced vertical hydraulic conductivity is common during the geothermal resource evaluations. However, specific modeling of the dome flanks has not been performed and the amount of data required to validate such a model is uncertain.

The discussion of data relating to the hydrologic features in the dome vicinity such as surface-water and ground-water interactions, pumping and injection centers, and fluid and matrix properties of the geohydrologic units (Section 3.3.2) has indicated that the data are sufficient to provide for preliminary geohydrologic characterization and modeling of the site. Hydrologic properties of the various units, particularly hydraulic conductivity and hydraulic gradient, are not well defined; however, sensitivity analyses performed during model calibration by Ertec (1983, ONWI-456, pp. 78-85) and INTERA (1983, ONWI-452, p. 49) have allowed estimates to be developed for these properties. This has provided greater confidence in modeling results by leading to better correlation of predicted heads with measured heads.

This indicates that it is reasonable to assume that the region around Richton Dome can be characterized and modeled with available techniques. However, complexities of certain features of the site raise uncertainties as to whether the site can be "readily" characterized.

The evidence indicates that the favorable condition is not present.

> (4) For disposal in the saturated zone, at least one of the following prewaste-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.

Evaluation. The boundary of the accessible environment is the margin of the salt stock and does not include adjacent sedimentary units. Although a Darcian model has been applied as a conservative approach to defining flow paths and rates within the Richton Dome salt (see Section 6.4.2.3.5), hydraulic conductivities and hydraulic gradients, while assumed to be very low, cannot readily be defined within a salt stock. This condition has been evaluated as follows:

1. The permeability of the salt host rock has been estimated to range from 10^{-2} to 10^{-7} millidarcys (see Section 6.4.2.3). The horizontal hydraulic conductivities for units surrounding the salt stock vary from 2.2 meters per day (7.2 feet per day) for the Upper Aquifer unit to 4.6×10^{-6} meter per day (1.5×10^{-5} foot per day) for the Vicksburg-Jackson confining unit in the direction of ground-water flow (Table 3-20). The host salt is considered to have extremely low vertical and horizontal hydraulic conductivity; the hydraulic conductivity of the surrounding units is variable. Subcondition (i) is not present.

2. Based on modeling results (Section 6.4.2.3.5), flow within the salt stock has a predominantly downward component due to the saturated brine within the pores of the salt. In the Lower Claiborne, Upper Claiborne, and Vicksburg-Jackson confining units, the hydraulic gradient is predominantly upward, with a small horizontal component. The flow path within the Wilcox Aquifer unit (beneath the Claiborne) is predominantly horizontal. It is uncertain whether any hydraulic gradient exists between the salt stock and surrounding sedimentary units. Subcondition (ii) is not present.

3. A low hydraulic gradient in and between the host rock and immediately surrounding geohydrologic units is expected to be found, but no data exist at this time to determine whether or not the condition can be found. Subcondition (iii) is assumed to be not present.

4. For the purpose of this assessment, the accessible environment is considered to lie at the margin of the salt dome. Undisturbed salt is essentially nonporous and is expected to have extremely low hydraulic conductivity (below current measurement capability). Without a basis for calculating an effective porosity in salt, Subcondition (iv) must be assumed to be not present.

In summary, a finding of present for favorable condition (4) requires the presence of one or more of the subconditions. None of the subconditions was found to be present.

The evidence indicates that the favorable condition is not present.

(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.

Evaluation. This condition applies to sites proposed in the unsaturated zone. The proposed level of the repository at Richton Dome is below the water table.

The evidence indicates that the favorable condition is not applicable.

6.3.1.1.3 Analysis of Potentially Adverse Conditions.

(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.

Evaluation. The conditions which would contribute to possible changes in the geohydrologic environment are related to climate changes, uplift or subsidence, and dissolution. It has been demonstrated that future climatic changes, based on past climatic extremes, will have a minimal effect on the ground-water system (Section 6.3.1.4). Furthermore, the likelihood that future tectonic processes such as uplift or subsidence will be disruptive is considered low (Section 6.3.1.7). Finally, the rate of Quaternary dissolution, if projected 10,000 years into the future, would not measurably affect the site (Section 6.3.1.6).

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. There are no ground-water sources along ground-water flow paths from the host rock to the accessible environment since this entire distance consists of the salt stock itself and salt stocks are not a source of water for any purpose.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. Folding and faulting occur within the Richton Dome area (Section 6.3.1.1). Little of the faulting or folding has significant expression in the geohydrologic units; that which does exist can be and has been modeled and characterized using available data. Modeling of the geohydrologic system will have to accommodate the vertical boundary of the dome flank. Although general models of fluid movement along dome flanks have been developed for use by oil and gas exploration companies, specific models to address flow along the flank of Richton Dome have yet to be developed and verified. For this evaluation it is considered that this could significantly contribute to the difficulty of modeling the dome flank.

The evidence indicates that the potentially adverse condition is present.

6.3.1.1.4 Analysis of Disqualifying Conditions.

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.

Evaluation. Pre-waste-emplacement ground-water travel times from the disturbed zone to the accessible environment along likely pathways are discussed in Sections 6.3.1.1.2 and 6.4.2.3.5. The travel times are based on conservative assumptions and statistical methods are employed to deal with parameter uncertainty. As discussed above, the travel times through the undisturbed part of the host rock have a median value of 3.5×10^7 years, respectively, and there were no travel times of less than 10,000 years.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.1.5 Conclusion For the Qualifying Condition. The site is located such that the present and expected geohydrologic setting of the Richton Dome site is compatible with waste containment and isolation considering the processes and characteristics operating within the geohydrologic setting. The ground-water travel time horizontally through the perimeter of the salt stock has been conservatively estimated. These estimates greatly exceed the 10,000-year guideline requirement. Hydrologic conditions present within the geqlogic media outside the Richton Dome site may have the potential to be affected by tectonic or climatic processes. However, evaluations about these processes conclude that projected hydrologic conditions will not adversely affect the proposed site's ability to contain and isolate waste during the next 100,000 years.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.2 Geochemistry, Guideline 10 CFR 960.4-2-2

The objective of the geochemistry Technical Guideline is to ensure that past, present, and expected geochemical characteristics of a site are compatible with waste containment and the engineered barrier systems. The guideline therefore addresses two aspects of the geochemical environment: the conditions that affect the release of radionuclides from the engineered barrier system and the conditions that affect the subsequent retardation of radionuclide migration in the geohydrologic system (e.g., conditions related to radionuclide precipitation or sorption and the formation of complexes or physical states that increase the mobility of radionuclides).

This guideline includes a qualifying condition, five favorable conditions, and three potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.3.1.2.1 Statement of 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.

Evaluation Process. This Technical Guideline requires an evaluation of (1) geochemical conditions within the host rock and surrounding units as these relate to the movement of radionuclides and releases to the accessible environment, and (2) geochemical conditions within the host rock that govern the nature and design of the engineered barrier system (e.g., the waste package). Engineered barrier performance is examined by estimating the composition and magnitude of fluids that will contact the barrier, barrier corrosion, and chemical controls on radionuclide releases. Results of the evaluation are summarized in Table 6-11 at the end of Section 6.3.1.

Relevant Data. Geochemistry data relevant to this guideline are those that describe the salt dome, adjacent sediments, and the fluids present in both. Site-specific data obtained during area characterization and generic data from other Gulf Coast salt domes are used, as follows:

- Mineralogy and chemical composition of salt and caprock (Sections 3.2.3.2 and 3.2.7.2), and adjacent sediments (Sections 3.2.3.2 and 3.2.7.1)

- Chemical composition of water in the adjacent sediments (Section 3.2.7.3) and fluid inclusions within the salt (Section 3.2.7.4)

- Data pertaining to chemical properties of evaporite minerals, brines, and behavior of selected radionuclides (Sections 3.2.7 and 6.4.2).

- Experimental and modeling results of candidate waste package component performance (Section 6.4.2)

- Radionuclide solubility data (Section 6.4.2)

- Data on dissolution processes at Richton Dome (Sections 6.3.1.6 and 3.2.5.7).

Assumptions and Data Uncertainty. Limited site-specific geochemical information is available for Richton Dome. One DOE borehole penetrates the salt (MRIG-9), and some ground water samples are available from wells in the area around the dome. Additional information is available from other Gulf Coast salt domes (in particular, several coastal domes). The actual amount of water contained in inclusions in the salt, the availability of organics in the salt, and the in situ effects of temperature and radiation are uncertain because site-specific data are limited. The expected uncertainties are accommodated in the analyses of Section 6.4.2 by assumption of conservative values.

Dome salt generally has a very low moisture content and is essentially impermeable (Tien et al., 1983, NUREG/CR-3129, pp. 207-211; ETC, 1984, BMI/ONWI-511, p. 26). Knauth and Kumar (1981) found water contents of 0.0001 to 0.007 weight percent in salt from Rayburn's and Vacherie Domes (Louisiana). Gevantman (1981, Table 1.4) reports brine contents between 0.01 and 0.02 weight percent for Avery Island dome salt and 0.004 and 0.040 weight percent for Weeks Island dome salt. Site-specific water content data are not available for Richton dome salt; however Roedder and Chou (1982, pp. 2-8) suggest that a water content of 0.1 weight percent is a conservatively high value for domal salts. Using conservative assumptions regarding the expansion of water upon saturation with halite and thermal expansion at 90 C (194 F), 0.1 weight percent water is equivalent to 0.26 volume percent brine (Section 3.2.7.4). To assure that brine volumes are not underpredicted, the waste package performance calculations for Richton Dome (Section 6.4.2) assume an initial brine content of 0.5 volume percent. Both fluid inclusion (thermally migrating) and intrusive brines are expected to be low-magnesium (about 120-130 milligrams per liter) sodium chloride types (see Table 6-31 in Section 6.4.2.3.2).

Analysis. The performance assessments and additional geochemistry information presented in Section 6.4.2 suggest the following:

1. Thermally-induced brine migration will bring only a moderate amount of brine in contact with the waste package, and the brine that accumulates will not destroy the ability of the waste package to meet the requirements of 10 CFR 60.113.

2. Waste package corrosion in unlimited quantities of low-magnesium brine will not lead to waste package failure within 10,000 years after burial for commercial high-level waste (CHLW). The spent fuel from pressurized-water reactors (SFPWR) overpack is estimated to last at least 4,800 years under these intrusive conditions.

3. A conservative analysis of expected conditions shows that less than 0.001 percent of the 1,000-year radionuclide inventory would dissolve per year.

4. There are no driving forces that would cause release of dissolved radionuclides from the repository.

Waste package corrosion by limited volumes of thermally-migrating high-magnesium (35,000 milligrams per liter) brine was also evaluated by Jansen (1985, Table 4b), who showed that both CHLW and SFPWR waste packages would be intact at 10,000 years under this condition.

6.3.1.2.2 Analysis of Favorable Conditions.

(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.

Evaluation. Geochemical processes that, if operative, could adversely affect the ability of the geologic repository to isolate the waste could include, but not be restricted to, the following: a) dissolution or hydrometamorphic alteration of the late-forming, soluble minerals, (for example, carnallite and kieserite); b) host rock alteration, such as sulfatization, secondary dolomitization, hydration and dehydration, by migrating hydrothermal brines; and c) large-scale salt dissolution. Carnallite and kieserite have not been identified in Richton Dome salt, and there is no evidence of alteration by migrating hydrothermal brines. Therefore, salt dissolution is the principal geochemical process that could potentially affect the ability of the repository to isolate waste. An analysis of the timing of caprock formation as the residuum of salt dissolution at Richton Dome is presented in Section 3.2.5.7. The caprock appears to have been completely formed by the late Oligocene, and there are no indications of significant ground-water movement through the lower caprock since that time. Discussion in Section 6.3.1.6 concludes that there is no evidence of significant Quaternary dissolution at Richton Dome and no evidence that continued dissolution, even at unlikely maximum rates, will lead to a loss of waste isolation within 10,000 years after repository closure. This evaluation was based on (1) evidence for a long-term (greater than 25 million years) hydrologic stability of the site; (2) consistently slow (less than 6 centimeters [2.4 inches] per 1,000 years and more likely less than 3 centimeters [1.2 inches] per 1,000 years) dissolution rate estimates based on reasonable geological constraints and conservative assumptions; and (3) the buffer zone of salt and anhydrite caprock, which is estimated to be at least 244 meters (800 feet), that will separate the repository from the nearest aquifer. Based on maximum dissolution rate estimates, waste isolation will not be affected by salt dissolution for at least 4 million years.

The evidence indicates that the favorable condition is present.

(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.

Evaluation. The geochemical conditions addressed in this guideline occur both inside the salt stock and in the sediments and ground water surrounding the dome, and are discussed accordingly in the following evaluation. Geochemical conditions outside the dome are described to provide background to this evaluation, but are not factored into the finding for the guideline. Since the edge of the dome is defined to be the accessible environment, only those geochemical conditions described within the salt stock are applied to the guideline finding.

1. Precipitation of Radionuclides in the Host Salt. Reduced forms of carbon (organic material), iron (pyrite), and sulfur (pyrite and elemental sulfur) are known to be present in the Richton Dome caprock (Drumheller et al., 1982, ONWI-277). The salt stock also contains minor amounts of pyrite and organic matter (Drumheller et al., 1982, ONWI-277). Fluid inclusions in the host salt contain hydrocarbons, with mean occluded methane contents of 0.64 microliters per gram (Mullin, 1982, p. 37; Drumheller et al., 1982, ONWI-277). The presence of reduced species such as methane and sulfides at least qualitatively suggests the existence of reducing conditions (Lindberg and Runnells, 1984), which will promote the precipitation of many redox-sensitive radionuclides such as technetium, neptunium, uranium, and plutonium. In addition, certain radionuclides (strontium and radium) will form relatively insoluble sulfates and/or carbonates (Langmuir and Riese, 1985; Stumm and Morgan, 1970).

Gamma radiolysis may alter ground-water redox states through the production of species such as hydrogen peroxide, oxygen, hydrogen, chloride, and possibly perchlorate (Panno and Czyscinski, 1984). Similar effects are predicted from alpha radiolysis of brines (Pederson et al., 1984), which will not occur until waste package failure. Brine radiolysis reactions have been experimentally documented at dose rates many orders of magnitude greater than that expected at the waste package surface, and will be localized to the near-field repository environment, should they occur (Levy and Kierstead, 1982, BNL-32004; Panno and Soo, 1983). If future research demonstrates significant brine radiolysis at expected repository dose rates, then engineering measures can be implemented to reduce radiation dose rates to minimize any associated adverse effects.

2. Precipitation of Radionuclides Outside the Host Salt. Ground waters surrounding the dome contain methane, ethane, hydrogen (Drumheller et al., 1982, ONWI-277; Russell, 1984), and sulfide (Section 3.2.7.3) and are considered to be chemically reducing (LETCo, 1982, ONWI-120, Vol. VII, p. C-3-13). Sedimentary units adjacent to the dome contain lignite, pyrite, siderite, and glauconite. Garrels and Christ (1965, pp. 209-224) show that the presence of siderite indicates a system with an Eh probably less than -100 millivolts. Russell (1984, pp. 19-20) reports Eh values averaging less than -17 millivolts in formation fluids from the Upper Aquifer unit. If a few suspect higher Eh measurements are discarded, then average Eh values are more on the order of -50 to -100 millivolts (Russell, 1984). Lindberg and Runnell's (1984) point out that obtaining reliable Eh measurements in ground water is problematic; however, the presence of redox-sensitive species such as sulfide and methane can provide at least a qualitative guide to the redox status of water. At redox potentials expected in the lower hydrostratigraphic unit, redox-sensitive radionuclides are expected to be stable in their lower oxidation states. The retention of radionuclides such as uranium, neptunium, plutonium, and technetium is greatly increased under reducing conditions because these elements form compounds having much lower solubilities than those formed under oxidizing conditions (Cleveland et al., 1983; Cleveland, 1979a,b; Bondietti and Francis, 1979; Langmuir, 1978).

3. Sorption. The domal salt consists of 91 percent halite, 8 percent anhydrite, and 1 percent dolomite, pyrite, quartz, plagioclase, calcite, and organic material (Section 3.2.7.2; Drumheller et al., 1982, ONWI-277). Nonsalt units adjacent to the dome are composed primarily of sand, clays, and carbonates, with minor amounts of lignite, glauconite, and pyrite (Section 3.2.7.3). Halite and anhydrite are not expected to contribute significantly to sorption (Meyer, 1979, PNL-SA-8571). The clays, lignite, and glauconite are expected to adsorb certain radionuclides, although such sorption is expected to be mitigated by the presence of brines (Muller et al., 1981, NUREG/CR-1996). While some radionuclide sorption is expected, the performance assessments in Section 6.4.2 conservatively do not take credit for retardation by sorption.

4. Colloid Formation. Brines promote the conversion of stable hydrophilic colloidal suspensions to unstable hydrophobic colloids (Stumm and Morgan, 1970, pp. 500-507). The conversion process is accompanied by colloid growth and charge reversal, resulting in large relatively immobile particles that can be more effectively filtered by geological substrates. Evidence on the deposition of plutonium-bearing particles and flocculation of organo-metallic colloids suggests that this phenomenon is operative in estuarine water and sea water (Hamilton, 1985; Coonley et al., 1971). However, the applicability of this phenomenon to site-specific domal salt environments needs to be established further as (1) there is no general quantitative theory which predicts the size to which hydrophobic colloids will grow, and (2) the ultimate transportability of such colloids in ground water will depend upon their size and charge characteristics as well as upon the hydrogeochemical characteristics of the repository environment.

5. Inorganic Complexes. The uranium-bearing species, $UO_2(CO_3)_3^{4-}$, which contains hexavalent uranium, can be thermodynamically stable under reducing conditions (Garrels and Christ, 1965, Figure 7.32b). Reduced plutonium may also complex significantly with certain inorganic ions (Cleveland, 1979b). The thermodynamic data base used for calculating radionuclide solubility and speciation in water is probably not adequate for definitive calculations. The effects of high ionic strength media, temperature, and pressure pose additional difficulties.

6. Organic Complexes. Site-specific organic geochemical data are not available for either deep formation fluids adjacent to the dome or for the host halite. However, acetate and other low molecular weight aliphatic acid anions are common anaerobic breakdown products of sedimentary organic matter, and it is likely that they occur in ground waters in the domal settings. Short-chain aliphatic acid anions have been identified in deep brines from the Palo Duro Basin in Texas (Means and Hubbard, 1985, BMI/ONWI-578) and have been tentatively identified in formation fluids from the Leadville Limestone underlying the Paradox Basin in Utah (McCulley et al., 1984). Carothers and Kharaka (1978) identified short-chain aliphatic acid anions in ground waters from the Houston and Corpus Christi areas of Texas, with acetate concentrations ranging up to 1,200 milligrams per liter. Acetate and propionate predominate in deep ground waters from the Iberia oil field in south-central Louisiana, with concentrations ranging up to 66 and 44 milligrams per liter, respectively (Workman and Hanor, 1985). While organic geochemical data on deep domal brines are lacking, if short-chain aliphatic acid anions are the principal organic species present, then significant radionuclide complexation would not be expected (Means and Hubbard, 1985, BMI/ONWI-578). Richton Dome salt stock contains hydrocarbons, including methane in concentrations of 0.64 microliters per gram. Formation fluids adjacent to the dome contain both methane and ethane (Drumheller et al., 1982, ONWI-277). The radiolysis of these organic gases will likely form polyethylene and/or low molecular weight organic species, such as formic acid, in addition to carbon dioxide and water (Lind, 1961; Gray, 1984). None of the expected radiolytic by-products possesses significant radionuclide complexation characteristics. The speciation and amount of organic matter contained in Richton Dome halite as inclusions, and possible effects on radionuclide complexation, have not yet been evaluated.

The evidence indicates that the favorable condition is present.

(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.

Evaluation. The host salt can undergo changes resulting from radiation and heat. Adverse effects from radiation are expected to be mitigated by the fact that the expected dose rate at the exterior of the overpack surface is only approximately 20 rads per hour (Jansen, 1985). Gamma irradiation of halite can produce sodium metal and free chlorine; however, the effect is very localized and experimentally documented for total doses exceeding 10^7 rads (Levy and Kierstead, 1982, BNL-32004; Panno and Soo, 1983). Also, if free chlorine does not evolve from the salt, the decomposition products may react back to form sodium chloride (Pederson et al., 1984). The radiolytic decomposition of halite has not been documented at expected dose rates of approximately 20 rads per hour at the waste package surface. If future research shows that such dose rates initiate processes that adversely affect rock strength, then engineering variables such as canister thickness can be adjusted to minimize such effects.

Clay minerals will undergo thermal dehydration resulting in changes in the physical properties of the affected clay-rich material, if located near the waste package. However, clay minerals are very minor constituents of domal salt and have been reported only in trace amounts in salt core from Richton Dome. Any associated volume reduction is expected to be totally offset by salt creep and expansion around the waste package.

Heat can cause migration of fluid inclusions up the thermal gradient, yielding brine to corrode the waste package (Sections 3.2.7.4 and 6.4.2.3.2). Fluid content of domal salt is very low. The amount of brine conservatively estimated to form by this mechanism is not expected to destroy the ability of the waste package to contain the radionuclides.

The halite (sodium chloride) and anhydrite (calcium sulfate) of the host rock are stable at temperatures far above those expected in the repository; that is, sodium chloride melts at 800 C (1,472 F) and calcium sulfate melts at 1,450 C (2,642 F) (Weast, 1984), whereas the maximum allowable repository temperature is less than 250 C (482 F). No information has been found that indicates that major evaporite phases might form a eutectic with a significantly lower melting point. Therefore, expected repository conditions are not likely to alter the ability of the mineral assemblages to retard radionuclide transport.

The evidence indicates that the favorable condition is present.

> (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.

Evaluation. Under expected conditions, water contacting the wastes will be restricted to brine inclusions in the salt, intergranular water, and very small amounts of water from the dehydration of hydrous minerals. The amount of brine contacting the packages has been conservatively calculated to be equal to or less than 0.26 volume percent at the dome sites (Section 3.2.7.4). Assuming a higher value of 0.5 volume percent brine, the assessments of waste package performance show that package failure is unlikely (Section 6.4.2). The expected release (none) demonstrates this favorable condition.

One set of conservative calculations investigates radionuclide release from hypothetically breached waste packages (Jansen, 1985). The critical assumptions are that (1) the waste package fails (NRC requires the waste package to last for at least 300 years); (2) as the brine reaches the waste package, it becomes saturated instantly with each radionuclide; (3) conservatively high saturation values for each radionuclide are used; and (4) no brine is consumed by reaction with the waste package. Jansen's calculations are summarized in Tables 6-34 and 6-35 of Section 6.4.2.3.3. These tables show that this favorable condition is met for the sum of all radionuclides prior to 1,000 years (note that the alternate condition of these tables is based on the 10 CFR Part 60 regulation, which requires a fractional release of 10^{-8} per year, while the favorable condition for this guideline is 10^{-5} per year summed over all radionuclides; i.e., sum the alternate condition tables and divide by 1,000 for comparison with the guideline. Therefore, the criterion is expected to be met.

Another set of conservative calculations made by Jansen (1985) assumes (1) ground water flows through the salt and (2) radionuclides are released as the matrix is dissolved. These assumptions are conservative in that significant ground-water flow is not expected in the rock salt, which has an extremely low permeability. The CHLW and SFPWR releases estimated by these calculations are still below the guideline rate of 10^{-5} per year needed for long half-life radionuclides.

The thermodynamic data base on radionuclide solubility contains uncertainties and assumptions. The solubility calculations will be updated as further information becomes available. The effect of radiolysis on geochemical conditions around the waste package is also not completely understood. Certain adverse effects have been noted at high dose rates such as 10^5 rads per hour (Kreiter, 1984, PNL-4250-4). Expected dose rates at the overpack surface are on the order of 20 rads per hour where little or no adverse radiation effects have been documented. The introduction of atmospheric oxygen during repository operation may create oxidizing conditions that are expected to be short-lived because of the consumption of oxygen by the metallic iron overpack (Jantzen, 1982).

The evidence indicates that the favorable condition is present.

(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.

Evaluation. The presence of clays, glauconite, and lignite is expected to promote sorption along paths outside the dome, and anoxic deep brines are expected to retard the migration of redox-sensitive radionuclides. However, insufficient evidence is available to quantify the decrease in the peak cumulative release.

The evidence indicates that the favorable condition is not present.

6.3.1.2.3 Analysis of 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 expected repository performance could be compromised.

Evaluation. For a repository in salt, the expected ground-water effect on the designed engineered barrier system is corrosion of the waste package by brine in the salt. The effects of this brine are estimated by the following set of calculations (Section 6.4.2): (1) the thermal conditions expected to result from the heat-producing waste are calculated; (2) using those thermal conditions and conservative estimates of the amount of brine present in the salt, brine migration calculations are performed to estimate the amount of brine that will migrate up the thermal gradient to each waste package; and (3) the extent of corrosion expected from this amount of brine is calculated. Brine composition and the effect of radiolysis on brine composition have also been factored into these calculations.

When the source of the brine is assumed to be produced by thermal migration of limited quantities (0.5 volume percent) of the low-magnesium brine, waste package lifetime has been calculated to exceed 10,000 years for both CHLW and SFPWR (Table 6-31 in Section 6.4.2.3.3). In the presence of an unlimited volume of a low-magnesium intrusion brine, the waste package lifetimes are expected to be 4,800 years for SFPWR and greater than 10,000 years for CHLW (Table 6-31 in Section 6.4.2.3.3). Calculations by Jansen (1985, Table 4b) also demonstrate waste package lifetimes for both CHLW and SFPWR in excess of 10,000 years for limited volumes (0.5 percent) of high-magnesium, thermally-migrating brines.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Halite, anhydrite, and trace concentrations of accessory phases such as quartz, dolomite, pyrite, and clays comprise the dominant mineralogy of the domal salt (Drumheller et al., 1982, ONWI-277). Evaporite minerals are not expected to contribute significantly to sorption processes. Clay minerals may contribute to the sorption of certain radionuclides, and clays in the vicinity of the repository may undergo thermal dehydration. There is no evidence that suggests that dehydration will reduce the sorption capacities of clay minerals, which are present in very low concentrations. Furthermore, the performance calculations (Section 6.4.2) conservatively assume no sorption. Consequently, further reduction in the assumed sorption capacity is not possible.

Geochemical processes that might degrade rock strength include the melting of host rock mineral phases, radiolytic decomposition of mineral phases, or thermal dehydration accompanied by volume reduction. Minerals present in the Richton Dome salt stock melt at temperatures far exceeding the maximum allowable repository temperature (250 C [482 F]), and eutectic phases with significantly lower melting points are not expected. At high radiation dose rates, halite may decompose to sodium metal colloids, chlorine gas, and other by-products. Such effects are documented only for radiation fields greatly exceeding expected conditions at the overpack surface, and the phenomena, when observed, are very localized (Levy and Kierstead, 1982, BNL-32004). Any small volume reduction accompanying clay dehydration is expected to be completely offset by salt creep and expansion around the waste package.

Appendix 6-A presents an evaluation of the extent of the expected "disturbed zone" around a repository in the Richton Dome. This analysis examines the disturbance of the salt by (1) mechanical impacts, (2) chemical conditions, (3) thermomechanical conditions, (4) thermohydrologic conditions, and (5) radiation effects. Results of these preliminary analyses indicate that the disturbed zone in the dome will not extend a significant distance from the edge of the repository workings. Decreases in rock strength beyond this narrow zone are not anticipated.

The evidence indicates that the potentially adverse condition is not present.

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

Evaluation. Richton Dome salt contains only minor amounts (likely less than 0.26 volume percent) of brine, which is present primarily as inclusions and intragranular water in halite. There is little direct evidence on the oxidation-reduction potential of water in the dome salt per se; however, the presence of elemental sulfur, pyrite, and organic material in the caprock and dome salt, and of methane and other hydrocarbons in fluid inclusions in the halite, are consistent with reducing conditions (Drumheller et al., 1982, ONWI-277; Mullin, 1982, p. 37). The environment adjacent to the dome salt is also very likely reducing because methane, ethane, and sulfide are present in the formation waters and lignite, pyrite, siderite, and glauconite occur in the sedimentary section (Drumheller et al., 1982, ONWI-277). Russell (1984, pp. 19-20) reports Eh values averaging less than -17 millivolts in formation fluids from the Upper Aquifer unit. Numerous Eh measurements fall in the range of -50 to -100 millivolts (Russell, 1984). Lindberg and Runnells (1984) indicate that the presence of redox-sensitive species, such as methane and sulfide, provide a useful qualitative guide to the redox state of ground water.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.2.4 Disqualifying Condition. There is no disqualifying condition for the Geochemistry Guideline.

6.3.1.2.5 Conclusion for the Qualifying Condition. Richton Dome salt contains small amounts of brine as fluid inclusions and intergranular brine in halite and presumably as hydration water in clay-minerals. Corrosion calculations based on deliberately overestimated brine volumes suggest that waste package failure will not occur within at least ten thousand years after repository closure.

Reducing conditions within the dome are expected to retard waste package corrosion and promote the precipitation of many redox-sensitive radionuclides; others may form insoluble sulfate and/or carbonate minerals or be adsorbed by glauconite, lignite, and clays in clastic strata surrounding the proposed repository horizon. Brine radiolysis reactions have been experimentally documented only at dose rates greatly exceeding those expected at the waste package surface and will be localized to the near-field environment, should they occur.

Deep basin brines may contain low molecular weight organic acids, which are weak complexing agents. Radiolysis reactions may form additional organic species that are not expected to possess significant complexation characteristics. Radiocolloid formation is expected to be minimized by the destabilizing effects of brines.

The host rock can undergo changes resulting from heat and radiation. Halite and anhydrite are expected to be stable at temperatures far above those expected in the near-field repository environment. Adverse effects from radiation are expected to be mitigated by the fact that the expected dose rate at the exterior of the overpack surface is only approximately 20 rads per hour. Preliminary assessments indicate little potential for salt dissolution to affect repository performance in the next 100,000 years.

In conclusion the Richton Dome salt environment is geochemically conducive to waste isolation should waste package failure occur. Assessments of waste package performance strongly suggest that the engineered barrier system will contain radionuclides for very long periods of time. This evaluation was conducted using demonstrably conservative assumptions.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.3 Rock Characteristics, Guideline 10 CFR 960.4-2-3

Postclosure rock characteristics are important to the long-term isolation capability of the host rock. The mining operations during repository construction and the heat generated by the emplaced wastes must not cause fractures or the thermal alteration of minerals that would significantly diminish the ability of the site to contain the waste. If extensive changes in the host rock occur, new pathways for radionuclide migration from the repository could result, and the isolation capabilities of the rock could be impaired.

This guideline includes a qualifying condition, two favorable conditions, and three potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.3.1.3.1 Statement of 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.

Evaluation Process. Richton Dome is evaluated against this guideline by considering the characteristics of the host rock and caprock as they are known from various investigations. The analyses evaluate whether the geometric and physical characteristics of the host medium are compatible with repository requirements. Compliance with the requirements referenced in the qualifying condition is addressed by performance assessment analyses described in Section 6.4.2. The results of the evaluation are summarized at the end of Section 6.3.1.

Relevant Data. Information on rock characteristics of Richton Dome has been obtained from drilling and geophysical surveys of the site and laboratory testing of core samples obtained from the borehole MRIG-9. Data relevant to this discussion are summarized in Table 6-9 and are discussed in detail in the following sections:

- Caprock and Salt Dome Stratigraphy (Section 3.2.3.2)
- Salt Dome Development and Geometry (Section 3.2.5.6)
- Rock Characteristics (Section 3.2.6)
- Geochemistry of Caprock and Salt Stock (Section 3.2.7.2).

Assumptions and Data Uncertainty. Data are limited and no testing has been done at the site. As discussed in Section 5.1, only preliminary repository designs have been developed. Because of this, the approach taken to the evaluations is qualitative rather than analytical. Many openings have been constructed in salt domes, and the problems encountered and solutions utilized are documented in the literature. The evaluation procedure involved identifying which conditions known to cause problems are likely to be present at the site and assessing the degree to which available technology is adequate to mitigate them, if present. The shape and size of Richton Dome have been defined based on data from petroleum exploration wells, seismic reflection surveys, and gravity studies. Uncertainty remains about the exact location of the dome flank at proposed repository levels but the areal extent of salt available at various depths can be estimated reasonably well. Petrologic, geomechanical, and thermal

Table 6-9. Summary of Rock Characteristics, Richton Dome, Mississippi[a][g]

Rock Characteristics	Range of Values[b]/Remarks
Caprock (Anhydrite)	
Density[1]	2.64 - 2.84 (g/cm^3)
Young's Modulus[2]	67.8 - 80.3 (GPa)
Poisson's Ratio[2]	0.33 - 0.47
Unconfined Compressive Strength[c][2]	71.2 - 102.9 (MPa)
Tensile Strength[c][2]	-6.9 - -5.9 (MPa)
Salt Stock (Halite)	
Density[1]	2.17 - 2.26 (g/cm^3)
Young's Modulus[2]	26.7 - 36.4 (GPa)
Poisson's Ratio[2]	0.21 - 0.55
Strength Behavior[2]	Mises-Schleicher Criterion[a]
Creep Behavior[2]	Exponential Creep Law[a]
Thermal Properties:	
Specific Heat[d][1]	0.218 - 0.223 (Cal/g-C)
Conductivity at 100 C[e][1]	2.66 - 4.17 (Watt/m-C)
Coefficient of Linear Expansion[f][1]	37.5 - 46.5 x 10^{-6}/K
Thermal Decrepitation[1][2]	None below 450 C
In Situ Stress[3]	Lithostatic[a]

(a) The rock characteristics are discussed in greater detail in Section 3.2.6.

(b) Conversion factors are contained in the Glossary.

(c) Typically, 5 unconfined compression tests and 3 indirect tension tests were conducted per rock unit at 24 C.

(d) Specific heat was determined from enthalpy data over a temperature range of 0 to 350 C.

(e) Thermal conductivity was based on Pyroceram 9606 calibration standard, and determined using steady-state comparative technique. Thermal conductivity is temperature dependent as shown in Figure 3-21.

(f) Coefficient of linear thermal expansion was determined over a temperature range of 50 to 250 C.

(g) Test conditions are discussed in detail in the sources (1), (2), (3).

Sources: (1) Lagedrost and Capps, 1983, BMI/ONWI-522, pp. 54-57.
(2) Pfeifle et al., 1983, ONWI-450, pp. 29, 35, 42, 53, 65.
(3) Hoek and Brown, 1980, pp. 95-101.

information was obtained from the one vertical borehole (MRIG-9) in the salt stock. Because a salt dome's internal structure is typically steeply dipping, data from this borehole cannot be assumed to be representative of the entire salt stock. Further site-specific laboratory and in situ information is required to quantify the spatial variability of geomechanical properties. However, it is assumed that properties of the salt in MRIG-9 are similar to salt properties in other Gulf Coast domes, suggesting that the generic data pertaining to salt are likely to apply to preliminary evaluations. The scale of tested specimens will also affect geomechanical test results. As discussed in Section 3.2.6, the Richton Dome samples are believed to be representative of the rock mass, but large-scale in situ testing is required to verify this assumption.

Analysis. Relevant analyses to this guideline include those related to dome configuration and geometry (Section 3.2.5.6), evaluations of the geomechanical properties and in situ stress conditions of the host rock (Section 3.2.6.1), and thermal properties of the caprock and salt (Section 3.2.6.2). Geomechanical and thermal properties and in situ conditions used in the evaluations are based on laboratory test data for Richton Dome and field testing and mining experience from other Gulf Coastal domes.

6.3.1.3.2 Analysis of Favorable Conditions.

(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.

Evaluation. Section 5.1 presents the physical characteristics of a high-level radioactive waste repository in Richton Dome. Tables 5-1 and 5-2 give the required physical dimensions of the waste disposal areas and the expected volumes of nuclear waste. At the proposed repository depth of 646 meters (2,120 feet), an area of 22.2 square kilometers (8.5 square miles) is available to construct and house the repository including suitable buffer zones. Considering the long ground-water travel times through the salt stock (Section 6.3.1.1), this area allows significant flexibility in locating the repository to ensure isolation.

Section 3.2.6 suggests that large scale anomalous features (anomalous zones) are not likely to be characteristic of interior domes such as Richton. However, if an anomalous zone were encountered and it were determined necessary to exclude it from the available repository area it still would not significantly limit the lateral flexibility. To evaluate this, some fundamental assumptions are necessary to estimate the zone of exclusion. For conservatism, the length of the zone is chosen to equal the longest axis of the dome (7 kilometers [4.5 miles]) and the width of the zone of exclusion is chosen to be 153 meters (500 feet), which would include more than just the anomalous zone (Section 3.2). Hence the area of exclusion would be 1.15 square kilometers (0.44 square miles). The cross-sectional area of the dome at a depth of -610 meters (-2,000 feet) MSL (22.2 square kilometers [8.5 square miles]) minus the area required for the repository (8.17 square kilometers [3.16 square miles]) equals the excess area of the dome (14.0 square kilometers [5.42 square miles]). When compared with the estimate of area which might be excluded (1.15 square kilometers [0.44 square miles]), it is apparent that the effect of such a zone would not significantly limit the lateral flexibility. Richton Dome possesses several thousand feet of vertical thickness. Therefore, Richton Dome is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the subsurface facility.

The evidence indicates that the favorable condition is present.

(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.

Evaluation. The individual properties of the host rock are summarized in Table 6-9 and are briefly discussed below. The host rock (salt) exhibits high thermal conductivity relative to other rocks (Clark, 1966, pp. 461-464). This will preclude large thermal gradients under the envisioned repository operating conditions. The coefficient of thermal expansion is high compared to most other rock types.

Rock salt exhibits sufficient ductility (or plasticity) (Lorenz et al., 1981, p. 12) to close and seal fractures, provided it is adequately confined and under sufficient pressure. Elevated temperatures should enhance this attribute of confined salt. The closure-sealing characteristics of confined rock salt under pressure are expected to be beneficial in the far field of the planned repository to prevent development of potential flow paths. Furthermore, the closure-sealing behavior associated with the ductility of salt should hasten consolidation of crushed salt that is backfilled into waste emplacement rooms. The backfill will also reduce the amount of room closure and, ultimately, the amount of subsidence as measured at the surface by up to 65 percent, depending on the characteristics of the backfill and the method of its emplacement. Consequently, stress states will possibly approach near-lithostatic conditions in the salt backfilled rooms and surrounding rock formations. In general, fractures induced in the disturbed zone of the repository (Section 6.4.2) will also tend to be closed by salt ductility effects, provided the salt is adequately confined.

Predictions of postclosure salt behavior lack precision because of the uncertainties in the salt material model and its parameter values. Qualitatively, however, a characteristic of salt is its ability to undergo large deformations without fracturing in the postclosure stress and temperature environment. Salt retains its plastic behavior despite the wide range of distributions and concentrations of impurities commonly encountered in evaporite mineralogy. Therefore, although the actual material parameter values are not known without uncertainty, the physical behavior of salt should reduce the stresses over time and limit or prevent fracturing.

Additional detail on the contributions of the thermal characteristics of the host rock to sealing of induced fractures is provided in Section 6.4.2.3.

The evidence indicates that the favorable condition is present.

6.3.1.3.3 Analysis of Potentially Adverse Conditions.

(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.

Evaluation. No unusual engineering measures are necessary to ensure waste isolation or containment.

Based on the present knowledge of the host rock characteristics, no foreseeable rock conditions would require engineering measures beyond the available technology for the construction, operation, and closure of the repository. If they are present, heterogeneities, discontinuities, and impurities may influence rock mass behavior and characteristics as discussed in Section 3.2.6. Features such as anomalous zones, gas and brine pockets, and joints and fractured caprock have been encountered in salt mining operations, including other Gulf Coast salt domes. Existing technology is normally utilized to manage these conditions.

Conditions which are encountered in Gulf Coast salt mines and could be potentially adverse in a repository are discussed below because they represent fractured conditions in the host rock that have the potential to become hydrologic pathways. However, it is not expected that these phenomena will extend far into the host rock (Section 6.4.2.3).

Rapid closure rates have been reported in some salt mines. This condition generally is related to the stress level induced in the host rock by high ratios of salt extraction. Closure rates, however, can be anticipated and controlled by appropriate design of repository openings (e.g. limiting extraction ratios) at the proposed depth.

There is little empirical data about the effects of heat on anomalous zones and on the stability of underground tunnels in salt, but this is expected to have a minimal impact on the long-term performance of the repository. A discussion on the uncertainty concerning the effect of heat on the underground tunnels and how this will affect reexcavation and support of the tunnels is given in Section 6.3.3.2.2(2). While thermomechanical calculations can reasonably predict the amount of room closure and far-field behavior due to creep in the salt host rock, they are not reliable in predicting the response of underground tunnels in the early stages of heating. There is also little field evidence to indicate what failure mechanisms are acting immediately around the mine openings when salt is heated. It appears, however, that the effect of heating will be to exacerbate any slabbing and spalling tendencies, but it is not known how serious an effect this may have on repository performance after the openings are backfilled.

Rock salt exhibits sufficient ductility (or plasticity) (Lorenz et al., 1981, p. 12) to close and seal fractures, provided it is adequately confined and under sufficient pressure. Elevated temperatures will enhance this attribute of confined salt. The closure-sealing characteristics of confined rock salt under pressure are particularly beneficial in the far field of the planned repository to prevent development of potential flow paths. Furthermore, the closure-sealing behavior associated with the ductility of salt will hasten consolidation of crushed salt that is backfilled into waste emplacement rooms. Consequently, stress states will approach near lithostatic conditions in the salt backfilled rooms and surrounding rock formations. In general, fractures induced in the disturbed zone of the repository also will tend to be closed by salt ductility effects.

During decommissioning, the base of any shaft will be filled with concrete. Thereafter the salt sections will be filled with crushed salt and the non-salt sections backfilled with dense earthen material. Bulkheads of impermeable material will be constructed at selected intervals during backfilling. Finally, the shaft will be capped with concrete (Section 5.1.4.2.2).

Preliminary shaft seal performance analysis (Section 6.4.2.3.5) indicates that ground-water flow through and around the shaft will probably be very small. A combination of both shaft and repository seals will reduce even further the likelihood of any ground water reaching the waste, thus ensuring isolation.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. The potential exists for thermally induced fractures in the immediate proximity of canisters (Fossum, 1983, ONWI-315, pp. 12-16). However, the ductility (plasticity) of rock salt will tend to limit the extent of fractures to a portion of the disturbed zone of the repository.

Halite, anhydrite, dolomite, and pyrite are the mineral phases that have been identified in the host rock (halite predominates, and dolomite and pyrite occur in trace quantities) (Section 3.2.3.2). Of these, only anhydrite offers the potential for being transformed to a hydrated phase. However, this transformation does not occur in the domal salt because any water in the salt is saturated with respect to sodium chloride, and anhydrite will not hydrate to gypsum except at lower salinities than those that occur in domal salt (Deer et al., 1966, p. 469).

Brine migration effects will depend on the amount of brine present in the salt at the proposed repository elevation (Section 6.4.2.3.2). Generally, domal salt tends to be very dry outside of any anomalous zones (Bradshaw et al., 1968, p. 649; Lorenz et al., 1981, pp. 17-21, 28), minimizing potential for brine migration. Based on available information, anomalous zones containing significant water or brine are not expected in Richton Dome (Sections 3.2.3.2 and 3.2.6). Fluid inclusions containing brine, compressed gases, and hydrocarbons are rare in the Richton Dome (Mullin, 1982, p. 37). However, in situ studies will be required to confirm the included water content throughout the dome interior. Possible radiation damage in salt repositories has been assessed previously as being confined to a narrow annulus of the waste canister and, therefore, is essentially insignificant for structural stability considerations (Bradshaw et al., 1968, pp. 646-658). Although the magnitude of the resultant effects for most of these phenomena is small, corrosion of the waste package as a result of brine migration is possible.

The evidence indicates that the potentially adverse condition is present.

> (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.

Evaluation. Analyses of the effects of heat on the natural conditions of the host rock (Section 6.4.2.3,) demonstrate that the heat generated by the waste would not significantly decrease the isolation provided by the host rock compared with pre-waste-emplacement conditions.

A potentially disruptive mechanism to isolation that considers all of the elements of the above condition is the thermal uplift expected to result from waste heat generation from a repository. Thermal uplift can cause stresses to develop in overlying strata, and may result in tensile opening of existing fractures in the caprock. This fracturing could increase the potential for interaction between ground-water-bearing zones in the hydrostratigraphic units and the salt stock. Given densities of highly saline brines and the minimal temperature rise at the salt dome edge, circulation systems driven by temperature are not likely to occur.

Repository scale thermomechanical analyses by the DOE (1981 DOE/NWTS-147[2]), and Russell (1979) show that vertical uplift at the surface caused by heating of the repository could be as much as 3 meters (9.8 feet) and not cause environmental concerns. For example, Loken et al. (1984, Table 7-3) calculated a maximum surface uplift of 1 meter (3.2 feet). This uplift is distributed gradually over the ground surface above the repository. This 1 meter (3.2 feet) does not represent a differential movement over a short distance that would cause significant shear distortion or cracking of the caprock. The finite element model used by Loken et al. (1984) accounted for heterogeneities of thermomechanical properties. Loken et al. (1984) ignored discontinuities such as joints and fissures not only because of a lack of data, but also because their omission would overpredict the thermomechanical response in another way. Because Loken et al. (1984) made an elastic calculation, they ignored any stress relief due to creep closure of repository excavations and compaction of room backfill. Therefore, much of the stress driving uplift would dissipate in the creep closure of the repository rooms and consolidation of crushed salt backfill.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.3.4 Analysis of Disqualifying Condition. The guidelines do not include a disqualifying condition related to rock characteristics.

6.3.1.3.5 Conclusion for the Qualifying Condition. Richton salt dome is a massive body of relatively pure halite. It is considered capable of accommodating the stresses expected from a repository, and to be compatible with the waste and engineered components.

Richton Dome is sufficiently large to allow adequate lateral and vertical flexibility in placing the repository at a depth of 646 meters (2,120 feet). There are 22.2 square kilometers (8.5 square miles) at this depth, allowing a minimum of 244 meters (800 feet) of perimeter pillar around the repository workings. Domal salt has high thermal conductivity and high ductility.

Mining methods in salt domes are proven techniques and require no engineering measures beyond reasonably available technology. Heat and radiation effects are localized phenomena in the immediate repository vicinity, and will not decrease the salt dome's ability to isolate waste. Thermally induced fractures may occur only within the immediate vicinity of waste packages.

Salt has the ductility to heal internal fractures (see Appendix 6A). A lack of significant quantities of brine or hydrous mineral phases within the salt indicates that hydration/dehydration reactions will be negligible. Brine migration toward the waste canisters will affect rock strength only in the immediate vicinity of the repository (within a portion of the disturbed zone).

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.4 Climatic Changes, Guideline 10 CFR 960.4-2-4

Climatic changes could, over time, alter the geohydrologic system at a site. The guideline for postclosure climatic changes focuses on changes that may favorably or unfavorably affect the ability of a repository to isolate waste after closure. Sites at which projected climatic conditions will not be likely to affect radionuclide releases would be preferred over sites at which those conditions could affect releases.

This guideline includes a qualifying condition, two favorable conditions, and two potentially adverse conditions for analysis. It does not have a disqualifying condition.

6.3.1.4.1 Statement of 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 likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, as well as geomorphic evidence of the climatic conditions in the geologic setting.

Evaluation Process. An evaluation of paleoclimate in the Richton Dome area provides the basis for projection of future climatic trends over the period of repository performance. Such an evaluation must consider global and regional climatic patterns during the Quaternary Period, as well as geomorphic evidence of the climatic conditions in the geologic settings of the geologic past.

Relevant Data. Paleoclimatic trends on a global scale are known from isotopic, paleontologic, and lithologic data from deep sea core samples. Information relevant to Richton Dome is given in the following sections:

- Erosional Processes (Section 3.2.2.2)
- Paleoclimatology (Section 3.2.2.3)
- Hydrology (Section 3.3.1.1).

Assumptions and Data Uncertainties. A basic assumption used in this analysis of climate is that future climatic changes will be similar in magnitude to those that occurred during the past 125,000 years, as indicated by the geologic and paleoenvironmental record of the Gulf Coast region. Temperature extremes during the last 125,000 years have been similar to the range of global temperatures over the entire Quaternary Period (Section 3.2.2.3). This assumption is reasonable since the mechanisms controlling climate change during the Quaternary are the same that are active today, and that are expected in the near geologic future. Moreover, the paleoenvironmental record (Section 3.2.2.3) indicates that the climate in the site region has not changed dramatically over the last 125,000 years.

Uncertainties exist about climatic change because the environmental conditions accompanying a future period of global warmth cannot be directly compared with the conditions present during the Sangamon period of global warmth. This is because of the unknown effects of increased atmospheric carbon dioxide on climatic conditions. However, overall climatic stability in the site region throughout the past 125,000 years (Section 3.2.2.3), gives some confidence that climatic conditions would not unduly fluctuate.

Uncertainties exist about the sea level rise expected during a future period of global warmth. The National Research Council Geophysics Study Committee (1977, p. 8) states that "in the present state of understanding, it is impossible to forecast what might happen to the Greenland and Antarctic ice caps as a result of a rise of several degrees in global average air temperature." However, no evidence is available suggesting that the Earth's glacial ice has ever melted completely, and a complete carbon-dioxide-induced melting of the world's glaciers has not been envisioned (Aronow, 1982, ONWI-278, pp. 8, 9). Therefore, a probable maximum sea level rise of 5 to 10 meters (16 to 32 feet) is expected (Section 3.2.2.1).

Uncertainties also exist because of a lack of site-specific information about the effect of broad climatic changes on the hydrologic processes such as rainfall, evapotranspiration, and runoff that may influence repository performance.

Analysis. Analyses that are relevant to this guideline include an evaluation of climatic patterns during the Quaternary Period (Section 3.2.2.3).

6.3.1.4.2 Analysis of Favorable Conditions.

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

Evaluation. The finding for this condition is based on an analysis of the past 125,000 years of regional paleoclimatic record and the surface-water systems at Richton Dome. It is reasonable to assume that future climatic conditions over the next 100,000 years will fall within the range of climatic conditions experienced in the past 125,000 years (i.e., climatic optimum to Wisconsinan glacial maximum). Projections based on the paleoclimatic record, as specified by the guideline, suggest that no dramatic shifts in climate will occur (Section 3.2.2.3). Furthermore, the characteristics of the surface-water system are such that the minor climatic changes that might occur will not have a significant impact.

Based on conditions during the climatic optimum (125,000 years before present), it was found that during a period of global warmth, only a slight increase in streamflow will occur and only in winter when evapotranspiration losses are reduced (Section 3.2.2.3). Similarly, based on the paleoenvironmental record from the Wisconsinan glacial maximum, it was found that during a period of glacial cooling, slightly greater precipitation and streamflow will occur in the winter months, but greater aridity will prevail during the summer. A decrease in sea level would occur during a glacial maximum. This would cause lowering in base level of the streams in the Gulf Coastal region. Based on regional studies of erosion rates during the Quaternary Period (Section 3.2.2.2), the rate of stream erosion (entrenchment) was low during the Wisconsinan glaciation when similar conditions prevailed. This low erosion rate would not present a hazard to a repository.

A rise in sea level of 5 to 10 meters (16 to 32 feet), which is analogous to what occurred during the Sangamon climatic optimum and which is postulated as a result of carbon dioxide-induced warming, will not result in inundation of the site. The site is at or above an elevation of 50 meters (164 feet) mean sea level.

The evidence indicates that the favorable condition is present.

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

Evaluation. Some changes in the hydrologic system are assumed to have resulted from sea level lowering because of the conversion of sea water into polar ice during periods of extensive glaciation. During the late Wisconsinan glaciation, sea levels in the Gulf of Mexico fell 100 to 130 meters (330 to 430 feet) below present sea level. Such regional changes, combined with modifications to the streamflow regimes and regional uplift, resulted in stream entrenchment throughout the region. The geomorphic evidence suggests that the magnitude of entrenchment was small, approximately 30 meters (100 feet) in major rivers such as the Red River in Louisiana (Kolb et al., 1983, ONWI-467, p. 83). This amount of incision would have had little effect on the ground-water system around Richton Dome (Section 3.2.2.2). The absence of any indication of major changes to the local hydrologic system in the geologic or paleobotanical record suggests that no period of significantly modified ground-water recharge occurred during the Quaternary.

The above evaluation suggests that Quaternary climatic changes do not appear to have had a significant observable effect on the hydrologic system. However, the phrase "little effect" in the favorable condition statement has been taken to mean "measurable changes." On the basis of existing information, it is not possible to state that no measurable changes occurred in the hydrologic system as the result of Quaternary climatic changes.

The evidence indicates that the favorable condition is not present.

6.3.1.4.3 Analysis of Potentially Adverse Conditions.

(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.

Evaluation. This condition is not applicable at the Richton Dome site because repository emplacement will be in the saturated zone.

The evidence indicates that the potentially adverse condition is not applicable.

(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.

Evaluation. The results of climatic changes at Richton Dome that could potentially affect the ground-water system are perturbations in recharge and the regional hydraulic gradient. However, the magnitude of these perturbations is such that the effects on radionuclide transport are insignificant. The paleoclimatic record, discussed in Section 3.2.2.3, suggests that slight increases in ground-water recharge will occur during periods of both global warmth and periods of glaciation. Such changes will be insufficient to increase significantly the ground-water flux (Section 6.3.1.1).

The regional hydraulic gradients have a potential to be increased by a decline in sea level during a period of global cooling. The total effect of such a change is not expected to be large because the maximum reasonably anticipated decline in sea level is only 130 meters (430 feet). The analysis presented in Section 6.4.2.4 indicates that gradient changes in the near-surface aquifer would be small. Such changes are expected to have little or no effect on waste isolation characteristics or on the water-bearing unit beyond the edge of the dome at the repository horizon (Section 6.3.1.1). In no way can climatic change affect the hydraulic conductivity or effective porosity of the geohydrologic units. Ground-water flux changes, therefore, are directly dependent on the hydraulic gradient changes, which will be minimal.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.4.4 Disqualifying Condition. This guideline has no disqualifying condition.

6.3.1.4.5 Conclusion for the Qualifying Condition. Richton Dome is located such that future climatic conditions will not likely lead to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1.

The paleoenvironmental record indicates that the climate of the geologic setting has been stable over the last 125,000 years. Geologic evidence suggests that global climatic changes over the Quaternary Period had very little effect on the surface-water and ground-water systems at Richton Dome.

Projections of climatic patterns suggest that future climatic conditions will be similar to those existing today. Therefore, changes in the hydrologic system, including hydraulic gradient and ground-water flux, will be minimal. Effective porosity and hydraulic conductivity will not change. These changes will not significantly increase the potential for transport of radionuclides to the accessible environment.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.5 Erosion, Guideline 10 CFR 960.4-2-5

The objective of the Technical Guideline on erosion is to ensure that erosional processes will not degrade the waste-isolation capabilities of a site. In evaluating the potential effects of erosion on waste isolation, the depth of the host rock is most important. The site should allow the underground facility to be placed at a depth sufficient to ensure that the repository will not be uncovered or otherwise adversely affected. The disqualifying condition in the guideline on erosion states that the minimum depth is 200 meters (656 feet); a depth of at least 300 meters (984 feet) is a favorable condition.

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

6.3.1.5.1 Statement of 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.

Evaluation Process. The Richton Dome site is evaluated with respect to the erosion guideline by considering the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion during the Quaternary Period over the Gulf Coast region as a whole. The rates of erosion that have been estimated for Richton Dome are then compared with rates of erosion estimated at other localities within the Gulf Coast geological setting. The results of this evaluation are summarized at the end of Section 6.3.1.

Relevant Data. The erosional processes of concern include both regional denudation and entrenchment of stream valleys. The rate at which these processes occur is a function of the combined effects of climatic, tectonic, and geomorphic conditions. The data relevant to evaluating these conditions are as follows:

- Physiography (Section 3.2.2.1)
- Erosional Processes (Section 3.2.2.2)
- Paleoclimatology (Section 3.2.2.3)
- Site-Specific Stratigraphy (Section 3.2.3.2)
- Uplift and Subsidence (Section 3.2.5.4).

Assumptions and Data Uncertainty. Modern rates of uplift have been calculated based on geodetic observations made over 70 years. These observations indicate an uplift rate of 1 to 1.8 millimeters per year (0.07 inch per year) ± 0.3 millimeter (0.03 inch) for this portion of the Gulf Coast (Section 3.2.5.4). Because the rate of uplift can have a direct effect on the rate of erosion, these geodetically measured rates represent an uncertainty in this evaluation.

This uncertainty is partially accounted for by the available geologic evidence that indicates a much lower average rate of uplift through the Quaternary Period (Section 3.2.5.4). The geologic setting has not changed significantly since the onset of the current regime marked by the end of the deposition of the Citronelle Formation. (Section 3.2.1). Therefore, the geodetically measured rates are high compared to the Quaternary uplift rate (Section 3.2.5.4). The cause of these high rates is unclear and will be studied during site characterization (Section 3.2.5.4).

Analysis. Analyses needed to evaluate whether or not the site meets this guideline include projecting Quaternary erosion rates and patterns over the period of repository performance and calculating the overburden remaining after the erosional processes have acted on the site. These analyses indicate that the rate of entrenchment estimated at 7 centimeters per 1,000 years (3 inches per 1,000 years) added to a regional denudation rate of 3 to 5 centimeters per 1,000 years (1 to 2 inches per 1,000 years) would result in net erosion of 0.12 meter (0.4 foot) over the dome in a period of 1,000 years. This estimate assumes stream entrenchment directly over the dome is concurrent with regional denudation. This is a conservative estimate because these processes are not necessarily additive.

6.3.1.5.2 Analysis of Favorable Conditions.

(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.

Evaluation. The repository will be at a depth of 646 meters (2,120 feet) (Table 5.1).

The evidence indicates that the favorable condition is present.

(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.

Evaluation. The erosion rate (stream entrenchment and regional denudation) estimated for Richton Dome of 0.12 meter per 1,000 years (0.4 foot per 1,000 years), projected over the repository period of 10,000 years, would result in removal of 1.2 meters (4 feet) of material. This would leave approximately 550 feet of overdome sediments above the caprock. Using small-sample statistics to evaluate calculated erosion rates from the region (Section 3.2.2), it is found that the chance that erosion might remove the entire thickness of overdome sediments is much less than one in one million (Baillieul, 1985).

The evidence indicates that the favorable condition is present.

(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.

Evaluation. The erosion rate estimated for Richton Dome is 0.12 meter per 1,000 years (0.4 foot per 1,000 years). Projected over the first 1 million years after repository closure, this rate would result in the removal of 120 meters (394 feet) of material. This erosion rate would leave a minimum of 31.4 meters (103 feet) of overdome sediments. Hence, it is unlikely that any portion of the overdome sediments could be removed entirely, exposing the caprock. Even if this were to occur, there still would exist approximately 6 to 65 meters (20 to 213 feet) of caprock and an average of 409 meters (1,341 feet) of salt stock to be removed before reaching the repository depth. Furthermore, this evaluation neglects the possibility that constant erosion over the next 1 million years is geologically unreasonable. The geological record has shown that erosion approximately equalled deposition over the Quatenary Period. Nevertheless, after one million years a repository at Richton Dome will meet this favorable condition. Furthermore, favorable condition (1) calling for emplacement of waste at a depth of over 300 meters (985 feet) will still be satisfied.

The evidence indicates that the favorable condition is present.

6.3.1.5.3 Analysis of Potentially Adverse Conditions.

(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.

Evaluation. No evidence of sustained extreme erosion during the Quaternary Period is found in the geologic setting of the site. Topographic relief within the geologic setting is low (Section 3.2.2.1). Quaternary deposits are present in the floodplains and in the terraces flanking most major streams along the Gulf Coast (Section 3.2.5.4). The geologic setting includes alternating periods of deposition and incision throughout the Quaternary. The regionally extensive terrace deposits (Section 3.2.5.4) indicate an approximate balance between erosional and depositional processes during the Quaternary.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. The geomorphic processes that have been in operation during the Quaternary have resulted in a long-term erosion rate of 0.12 meter per 1,000 years (0.4 foot per 1,000 years). Such a rate, operating over a period of 10,000 years following repository closure, indicates that geomorphic processes will not adversely affect the ability of a geologic repository to isolate waste.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.5.4 Analysis of 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.

Evaluation. The vertical and horizontal extent of the salt below a depth of 200 meters (656 feet) at Richton Dome (Section 3.2.5.6) provides flexibility in selecting the depth and layout of the underground facilities. The current conceptual design (Section 5.1) calls for the repository to be located on one level at a depth of 646 meters (2,120 feet).

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.5.5 Conclusion for the Qualifying Condition. Richton Dome is located such that waste can be placed at sufficient depth so that erosional processes acting on the ground surface will not be likely to lead to radionuclide releases greater than those specified in Section 10 CFR 960.4-1.

At Richton Dome waste will be emplaced at a proposed depth of 646 meters (2,120 feet). The dome is situated in a geologic setting where the erosional processes operating during the Quaternary have resulted in an erosion rate of 0.12 meter per 1,000 years (0.4 foot per 1,000 years). Such a rate, operating over 10,000 years, would not increase the probability of radionuclide releases to the accessible environment. The amount of rock and salt remaining after one million years is in excess of the minimum emplacement depth. Topographic relief within the geologic setting is low and the presence of Quaternary deposits in stream terraces suggests that sustained extreme erosion did not occur during the Quaternary Period. The Quaternary erosion rate projected over 10,000 years will not adversely affect the ability of the repository to isolate waste.

Therefore, on the basis of the above evaluation the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.6 Dissolution, Guideline 10 CFR 960.4-2-6

The objective of the Technical Guideline on dissolution is to ensure that dissolution processes will not adversely affect the waste-isolation capabilities of the site. The principal concern is that the dissolution of the host rock might create new pathways for radionuclide migration to the surrounding geohydrologic system. The sites that have salt as the host rock are the most vulnerable to dissolution, and the effects of salt dissolution on waste isolation will be an important consideration in evaluating a site in salt.

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

6.3.1.6.1 Statement of 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.

Evaluation Process. The potential for significant dissolution at Richton Dome is evaluated in the context of the dissolution history and hydrogeologic regime of the site. The dissolution history was determined by examining the geologic setting for geologic and geochemical evidence of dissolution. This history defines the most likely periods of dissolution and allows estimation of long-term dissolution rates. The existing hydrologic regime provides a perspective in which to interpret possible geochemical evidence of dissolution and a basis for evaluating the appropriateness of making projections based on historic dissolution rates.

Central to this evaluation is the significance of dissolution events to the waste-isolation characteristics of the site. It is reasonable to assume that some dissolution can occur without adversely affecting the performance of the site. For the purposes of this evaluation, dissolution is considered significant if one of the following is true:

1. The rate of dissolution for the Quaternary Period, when projected over a period of 10,000 years, suggests changes in the geologic setting that could lead to radionuclide releases greater than those specified by the guideline.

2. Dissolution at the site during the Quaternary Period modified the geologic or hydrogeologic setting sufficiently to suggest that future dissolution is likely to occur at more rapid rates and could lead to radionuclide releases greater than those specified by the guideline.

Evaluation of this guideline does not address the effects of existing boreholes on the potential for dissolution at the site. These are human-induced effects and are considered in the analysis of potentially adverse conditions (c)(3) under the Natural Resource guideline (10 CFR 960.4-2-8-1). Furthermore, this evaluation examines only the potential for dissolution at the perimeter of the salt stock. Naturally occurring dissolution pathways or pockets of undersaturated water have not been encountered during mining operations in domed salt (Section 3.3.2.1).

Relevant Data. The data used for dissolution analyses are summarized in Section 3.2.5.7. These data are associated with the following aspects of dome geology relevant to the discussion of dissolution:

- Structural features (Section 3.2.5)
- Topographic features (Section 3.2.2.1)
- Caprock and salt stock hydrology (Section 3.3.2.1)
- Ground-water flow system (Section 3.3.2.1)
- Ground-water quality (Section 3.3.2.3)
- Geochemistry of ground water in sediments (Section 3.2.7.3)
- Caprock formation (Section 3.2.5.7)
- Overdome stratigraphy (Section 3.2.3.2)

These features, and their relation to the dissolution process, are discussed below.

Assumptions and Data Uncertainty. The history of past dissolution at Richton Dome is interpreted, and the potential for future dissolution is projected, based on geologic, geochemical, and hydrogeologic conditions at the site. Uncertainties about this assessment of dissolution are associated with the following:

- Level of detailed knowledge about the near-dome geologic setting

- Nature of evidence for Quaternary dissolution (i.e. granular anhydrite and the saline anomaly)

- Presence of fracture permeability in caprock

- Three-dimensional variability in caprock characteristics.

Analysis of the potential for dissolution at Richton Dome depends on interpretation of the near-dome geologic setting, particularly the overdome stratigraphy and structure (Werner, 1985a). The preferred interpretation of Werner (1985a) does have limitations resulting from data uncertainties and variability of natural systems. Furthermore, the evaluation of other potential interpretations of Werner's findings (Section 3.2.5.7) suggests that reasonable alternatives from his preferred geologic interpretation do not alter conclusions relative to the guideline.

Granular anhydrite accumulation at the base of the caprock at Richton Dome has been cited as evidence of active dissolution (i.e., granular anhydrite accumulated recently enough that it has not been incorporated into caprock) (Section 3.2.5.7). A conclusion about the timing of dissolution is relative and is based on theory of caprock formation rather than actual dating of the accumulation. Werner (1985a) interprets the two reports of granular anhydrite at the base of Richton Dome's caprock as post late-Oligocene, suggesting that salt dissolution that formed the accumulations could have occurred some time during the past 25 million years. Given this interpretation, some dissolution could have occurred during the Quaternary. However, regardless of when the dissolution occurred, the rate of dissolution was slow enough that collapse of the caprock and overburden have not been identified (i.e., the rate of dissolution did not greatly exceed the rate at which postdiapiric upward movement of the salt stock could adjust for the salt loss). Also, the uncorroded appearance of individual grains in the granular anhydrite, and the presence of fluids with very high salinities, indicate stagnant water conditions not conducive to active dissolution.

Some uncertainty remains with respect to the origin of increased concentrations of sodium chloride in the Upper Aquifer south of Richton Dome (i.e., the saline anomaly). Dual induction logs, water chemistry data, and the lithology of the project borings were reevaluated and correlated to produce an integrated conceptual model (Section 3.2.5.7). The reevaluation suggests that the anomaly may be naturally occurring, but is not related to dissolution of the Richton Dome salt stock. Rather, the salinity may be the result of incomplete flushing of connate water trapped in the formation (Section 3.2.5.7).

The low inherent permeability of crystalline anhydrite (Section 3.3.2.1) and lateral continuity of caprock over the crest and upper flanks of Richton Dome (Section 3.2.3.2) suggest that the anhydrite caprock may impede the flow of under-saturated ground water past the salt stock, thus reducing the potential for dissolution. This property of the caprock can be expected to be reduced where open fractures are present in the anhydrite. Werner (1985b) observed three fracture systems in the anhydrite core from MRIG-9. However, most of the fractures are filled with gypsum, which has greatly reduced the permeability of the fractures. Based on his observations, Werner (1985b) concludes that fluid movement in the present anhydrite caprock is likely to be predominantly through zones of open fractures, and that the volume of flow may be expected to diminish toward the base of the caprock.

General characteristics of the caprock and caprock-salt interface (geologic and hydrologic) are based on areally extensive drill hole data (Section 3.2.3.2); detailed data are available only from the MRIG-9 borehole. The lack of data to establish a detailed three-dimensional perspective of the caprock results in some uncertainty about variability of caprock fracturing. An assumption that the nature of caprock fracturing at MRIG-9 is representative of fracture caprock over other parts of the dome appears reasonable in the perspective of the uniformity of overdome structure (Section 3.2.3.2). Based on the description of the caprock-salt contact in seven sulfur exploration holes and experience at other Gulf Coast salt domes, it is also reasonable to assume that granular anhydrite is not everywhere present at the base of the caprock at Richton Dome.

Analysis. Analysis of the potential for dissolution at Richton Dome includes determination of the site's dissolution history and estimation of past dissolution rates based on caprock thickness. The technical basis for analysis of dissolution potential is described in Section 3.2.5.7. Specific data uncertainties associated with the analysis are described above.

6.3.1.6.2 Analysis of Favorable Condition.

> No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.

Evaluation. There is no direct evidence of Quaternary dissolution at Richton Dome. Thus, analysis of the favorable condition examines the implications to this assessment if certain evidence of dissolution at the site is assumed to be the result of Quaternary dissolution.

Preferred Interpretation. Structural and statigraphic relationships among overdome sediments and the caprock at Richton Dome suggest that dissolution resulting in caprock formation began during the Eocene and ceased by Late Oligocene, approximately 25 million years ago (Section 3.2.5.7). This interpretation of the dissolution history of Richton Dome yields an estimated dissolution rate of 3 to 5 centimeters per 1,000 years (1 to 2 inches per 1,000 years) (Section 3.2.5.7). Hence, any subsequent dissolution (i.e. during the Quaternary) was very minor, if it occurred at all, as evidenced by the lack of subsidence features over the dome.

Alternative Interpretations. Although the preferred interpretation presents an integrated analysis of geologic conditions, several geologic alternatives were examined to assess what impact they might have on the dissolution potential for Richton Dome.

An alternative interpretation is obtained if the overdome sediments are assumed to be only Miocene- and Pliocene- age units. This variation would suggest that the caprock ceased to form about 20 million years ago rather than the previously mentioned 25 million years. The estimated rate of dissolution for this scenario is approximatley 3 to 4 centimeters per 1,000 years (1 to 1.6 inches per 1,000 years). The evaluation of Quaternary dissolution would remain unchanged.

An alternative interpretation can be obtained if the caprock formation began in the middle to late Olgiocene and continued into the Quaternary. Hence, the gypsum-veining event within the caprock occurred much later than suggested in Section 3.2.5.7. Therefore, the accumulation of gypsum in the caprock formation is assumed to be the result of ground-water circulation during the Quaternary. However, such an assumption seems somewhat unreasonable in perspective of the sequence of fracturing and filling and the lack of evidence for net dome growth since the Miocene (Section 3.2.5.7). Nevertheless, the estimated dissolution rate under this scenario would be 3 to 4 centimeters per 1,000 years (1 to 1.6 inches per 1,000 years). This rate would have resulted in approximately 60 to 80 meters (200 to 260 feet) of salt dissolution during the Quaternary Period (2 million years).

A final alternative was examined by assuming that the accumulation of granular anhydrite at the base of the caprock is the result of localized dissolution during the Quaternary Period. Additional conservatism can be applied by assuming that this dissolution occurred over one quarter of the Quaternary (i.e., 500,000 years). Therefore, the 1.5 meters (5 feet) of granular anhydrite at the MRIG-9 borehole is assumed to represent dissolution of 15 meters (50 feet) of salt. Rates of dissolution based on this interpretation are less than 4 centimers per 1,000 years (less than 1.6 inches per 1,000 years) (Section 3.2.5.7). This alternative is less likely as it ignores the time period between 25 million years ago and the beginning of the Quaternary Period. The granular anhydrite is more likely to have formed in the last stages of the major caprock formation events when fractures were known to be open to undersaturated waters. Evaluation of the Quaternary-aged Citronelle Formation does not indicate uparching of the salt stock during this time period sufficient to renew caprock fracturing and connections to the overlying aquifer.

Section 3.2.5.7 indicates that a reported salinity anomaly south of Richton Dome is most likely due to incomplete flushing of less permeable units at the base of the Upper Aquifer. If this evaluation is discounted, then it can be assumed that the anomalous salinities may be the result of dome dissolution. Uncertainties about the distribution and magnitude of anomalous salinities do not allow meaningful estimates of the volume of salt dissolved or the rate of dissolution. Such dissolution would have to be recent as ground-water flow velocities in the Upper Aquifer would have resulted in a flushing of salinities from earlier known dissolution events (Murphy, 1985). However, evaluations of overdome stratigraphy do not indicate significant reduction of the salt stock due to dissolution within the Quaternary Period (Section 3.2.5.7).

The magnitude and rates of dissolution suggested by this analysis of possible Quaternary dissolution do not represent significant dissolution. Sufficient data on the stratigraphy and structure of overdome sediments are available to support the conclusion that any dissolution that may have occurred during the Quaternary did not substantially modify the hydrogeologic setting. Future dissolution at rates postulated by this analysis would not be significant nor jeopardize waste isolation.

The evidence indicates that the favorable condition is present.

6.3.1.6.3 Analysis of Potential 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.

Evaluation. Breccia pipes and natural dissolution cavities are features occasionally associated with bedded-salt deposits, but they have not been found at Richton Dome. The presence of caprock, if viewed as a volume reduction of the salt stock, is an indication of past significant dissolution. However, the absence of observed structural collapse or major thickening of the strata over the dome indicates that the volume reduction of salt subsequent to the formation of the caprock (i.e., post late-Oligocene) was not significant. This suggests that a hydraulic interconnection that could result in a loss of isolation is highly unlikely to occur. However, a literal reading of the guideline requires a statement that the potentially adverse condition is present.

The evidence indicates that the potentially adverse condition is present.

6.3.1.6.4 Analysis of the Disqualifying Condition.

> The site shall be disqualified 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.

Evaluation. This disqualifying condition specifically addresses the potential for a hydraulic connection between a repository and the surrounding geohydrologic units within 10,000 years. The prolonged period of hydrologic isolation over the past 25 million years, as determined by the caprock thickness and geologic relationships, is qualitative evidence that the site should remain stable for an additional 10,000 years.

Estimates of past dissolution rates are also based on caprock thickness and geologic relationships observed at the site (Section 3.2.5.7). Estimated rates for dissolution during caprock formation range from 3 to 5 centimeters per 1,000 years (1.2 to 2 inches per 1,000 years). Estimated rates for dissolution occurring after most of the caprock had formed (i.e., dissolution related to the accumulation of granular anhydrite) are less than 4 centimeters per 1,000 years (less than 1.6 inches per 1,000 years) if it is assumed that this dissolution occurred in the Quaternary. Over a period of 10,000 years, a total of only 0.6 meters (2 feet) of salt would dissolve at the maximum estimated rate. This total is not significant when compared to the minimum 244 meters (800 feet) of buffer zone that will separate the repository from the adjacent geohydrologic system.

Therefore, the evidence supports a finding that the site is not disqualified (Level 1).

6.3.1.6.5 Conclusion for Qualifying Condition. There is no evidence of significant Quaternary dissolution at Richton Dome and no evidence that continued dissolution, even at unlikely maximum rates, will lead to a loss of waste isolation within 10,000 years after closure of the repository. The most significant factors contributing to this assessment are as follows:

- Consistently slow (less than 5 centimeters per 1,000 years [2.4 inches per 1,000 years] and, more likely, less than 3 centimeters per 1,000 years [1.2 inches per 1,000 years]) dissolution rates and small magnitudes of dissolved salt (less than 0.5 meter [2 feet] through 10,000 years) that are estimated using reasonable geologic constraints and conservative assumptions

- The minimum 244-meter (800-foot) buffer zone of salt and the anhydrite caprock that will separate the repository from circulating ground water.

Therefore, when projected to 10,000 years, the magnitude of estimated dissolution is not considered significant and is not likely to lead to radionuclide releases greater than those allowable under requirements specified in 10 CFR 960.4-1.

Based on the above evaluation, the evidence supports a finding that the site is likely to meet the qualifying condition (Level 3).

6.3.1.7 Tectonics, Guideline 10 CFR 960.4-2-7

Meeting the requirements of the postclosure guideline on tectonics will provide a high degree of confidence that tectonic processes will not adversely affect the waste-isolation capabilities of the site. Tectonic processes and events during the postclosure period could adversely affect waste containment and isolation by creating new ground-water pathways to the accessible environment, altering ground-water travel times, or physically altering the local waste environment. Although it is difficult to predict geologic processes with certainty, this guideline requires that the tectonic history of a site be carefully examined and the results of this examination be used to determine if the likelihood for significant future tectonic activity is acceptably small. Igneous activity, uplift, subsidence, folding, and faulting are all important tectonic processes and are included in this guideline.

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

6.3.1.7.1 Statement of 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 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.

Evaluation Process. The Richton Dome site is evaluated against the tectonics guideline by considering the geologic and tectonic development of the Mississippi Salt Basin since the deposition of the Louann Salt in Jurassic time (about 160 million years ago). The older tectonic events in this time span provide the framework of tectonic structures within which the Quaternary tectonics are evaluated. Faults, regardless of their age of origin, are characterized as to whether they have been active during the Quaternary. This evaluation primarily uses stratigraphic and geomorphic evidence, and also considers reasonably associated seismicity. Similarly, the fold structures of the region (including basins and domes) are evaluated using geomorphic, stratigraphic, and geodetic data to determine if they are currently active. The results of this evaluation are summarized at the end of Section 6.3.1.

Relevant Data. Data on the tectonic framework of the region have been derived from numerous published sources and are summarized in Section 3.2.5. Supporting stratigraphic and structural data also have been acquired from completion records and geophysical logs of petroleum industry wells and interpretations of petroleum industry seismic profiles. The stratigraphy and structure of the area near the site were further evaluated by borings and surface mapping during area characterization. Tectonic processes and relevant physical properties are discussed as follows:

- Physiography (Section 3.2.2.1)
- Erosional Processes (Section 3.2.2.2)
- Faulting (Section 3.2.5.1)
- Seismicity (Section 3.2.5.2)
- Igneous Activity (Section 3.2.5.3)
- Uplift/Subsidence (Section 3.2.5.4)
- Folding (Section 3.2.5.5)
- Salt Dome Development and Geometry (Section 3.2.5.6)
- Thermal Properties (Section 3.2.6.2)
- Geomechanical Properties (Section 3.2.6.1).

Additionally, a study by McClure (1981) examined earthquake damage to underground structures for 107 cases in eight countries. These processes and their relation to tectonics are discussed below.

Assumptions and Data Uncertainties. The geologic history and tectonic evolution of the region and its salt domes are known generally from extensive mineral resource exploration. Nonetheless, the character of the data at the Richton Dome site requires that several assumptions be made for this evaluation.

The geologic setting and tectonic setting for Richton Dome are taken to be the Mississippi Salt Basin, which is bounded by the Pickens-Gilbertown fault zone on the north, the Mobile Graben on the east, and the Wiggins uplift on the south. The Mississippi Salt Basin extends westward into eastern Louisiana, but the western edge of the geologic setting is taken to be approximately coincident with the Jackson Dome. The bounding features, as well as more distant tectonic features, can affect the site only indirectly, such as by generating earthquakes felt at the site.

The rate of modern regional uplift is uncertain. Geodetic (releveling) data for the period from 1934 to 1969 suggest that short-term uplift may be occurring at a rate much greater than the long-term rate indicated for the entire Quaternary Period by the geologic data. As discussed in Section 3.2.5.4, the regional geomorphology shows the uplift rates calculated from the releveling data are not reasonable estimates for long-term rates. The discrepancy between short-term and long-term rates may result from systematic errors in the leveling surveys, or short-term variations in uplift rates. These data will be reevaluated during site characterization.

The analysis assumes that the historic seismicity record combined with the geologic and tectonic data are adequate to estimate large future earthquakes and to predict whether seismicity will affect postclosure performance. The seismicity data are extremely useful indicators of the current tectonic environment, but cannot be used alone to establish the potential seismic hazard.

There is some uncertainty about the southern extent of the New Madrid fault zone. This analysis uses the current interpretation, from studies sponsored by the U.S. Geological Survey and the U.S. Nuclear Regulatory Commission, which places the closest approach of the fault zone about 400 kilometers (250 miles) north-northwest of the site. If further studies extend the zone southward, it would likely end at the front of the buried Ouachita Mountains about 240 kilometers (150 miles) distant, or pass about 190 kilometers (120 miles) from the site. No faulting hazard at the site is expected from the New Madrid fault zone.

Analysis. Analysis of the tectonic setting of Richton Dome uses published reports and the results of area characterization studies. No structures in the tectonic setting are known to have been active during the Quaternary Period, nor was there any known igneous activity. Uplift occurred during the Quaternary Period, but at exceedingly slow rates. Some geodetic data suggest that short-term uplift may be occurring at more rapid rates.

The seismicity of the region was analyzed by considering the historical record of felt and instrumentally recorded earthquakes, and by integrating the seismicity data with the geologic and tectonic data. The tectonic setting is characterized by low seismicity and has no seismically active structures.

6.3.1.7.2 Analysis of 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.

Evaluation. Analysis of the probability of occurrence of future tectonic events includes a probability analysis for the joint failure of both geologic barriers and engineered barriers of a repository. Such analysis requires site-specific data and design-specific data that are not yet available. The tectonic data discussed below indicate very low likelihoods for the occurrence of disruptive tectonic events, and this indicates the favorable condition will be met.

No igneous activity has occurred in or near the Mississippi Salt Basin since at least the Cretaceous Period, about 60 million years before the Quaternary Period (Section 3.2.5.3).

The Mississippi Salt Basin has experienced only slow uplift and erosion since the early Quaternary. The rate of Quaternary uplift has been calculated using the estimated uplift rate of the Plio-Pleistocene Citronelle Formation (Section 3.2.5.4). The resulting rate, 0.1 meter per 1,000 years (0.04 foot per 1,000 years), is similar to other uplift rates reported in the Gulf Coast geologic setting (Section 3.2.5.4).

An uplift rate of 1.0 to 1.8 millimeters per 1,000 years (.04 to .07 inch per 1,000 years) has been suggested from reevaluation of the geodetic data. These data have been evaluated for possible systematic errors in measurement or complications introduced by analysis (Section 3.2.5.4). These rates do not appear to be reasonable long-term rates for the Gulf Coast region. The Citronelle Formation, Plio-Pliestocene in age and older than 10,000 years, is exposed in hills over the dome as a result of regional uplift rather than domal uplift. Field evidence available at this time does not indicate any deformation of the Citronelle Formation, as would be indicative of domal uplift.

Faults are present in the site vicinity and within the site's geologic setting (Section 3.2.5.1). Other faults in the Miocene Hattiesburg Formation may be present over the dome, but their possible presence is based on questionable interpretations of geoelectric profiles from shallow boreholes. The current data indicate that none of these faults has been active in the Quaternary Period. Evidence includes the absence of topographic expression and the presence of unfaulted overlying strata. However, detailed field studies are needed to prove conclusively that the faults have not moved in the Quaternary. Any overdome faults would provide useful indicators of the dome's most recent growth history, but do not themselves influence dome stability. The apparent lack of Quaternary faulting over the dome indicates stability (sufficient to preclude faulting) over the past two million years.

The Phillips Fault, which may pass about 8 kilometers (5 miles) east of Richton Dome, is probably Jurassic in age and clearly separated from Richton Dome (Section 3.2.5.1.). The trend of the fault is similar to that of the dome and the salt ridges from which domes have risen, so the origin of these features may ultimately be related to similar, deep geologic processes.

Folds, where present, are generally associated with the faults and also have not been active during the Quaternary.

The evidence indicates that the favorable condition is present.

6.3.1.7.3 Analysis of Potentially Adverse Conditions.

(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.

Evaluation. Analyses of folding, faulting, subsidence, uplift, and igneous activity are summarized in Section 6.3.1.7.2 (Analysis of Favorable Condition). Regional uplift has occurred during the Quaternary Period, whereas the other processes have not.

Diapirism does not appear to have occurred at Richton Dome during the Quaternary Period. Undeformed post-Citronelle-aged terraces indicate no warping after the Citronelle Formation was laid down, and the morphology of the Citronelle/Hattiesburg contact indicates that warping of the sediments above Richton Dome ceased prior to deposition of the Citronelle Formation (about 4 million years ago). These data are discussed in Section 3.2.5.6. From late Oligocene to early Pliocene, growth of the Richton salt stock was at a postdiapiric rate of only 0.6 to 2.6 centimeters (0.2 to 1.0 inches) per 1,000 years.

The evidence indicates that the potentially adverse condition is present.

(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.

Evaluation. The nearest known earthquake epicenter to Richton Dome is 75 kilometers (45 miles) away (Section 3.2.5.2). The maximum historical seismic shaking experienced at the site is estimated to be Modified Mercalli Intensity (MMI) V-VI from the 1811-1812 New Madrid, Missouri, earthquakes. The maximum earthquake estimated for the site region is magnitude 5.3 (MMI VI-VII) (Nuttli and Herrmann, 1978, pp. 14, 78). Such an earthquake could produce a peak ground acceleration of about 0.14 gravity (mean-value estimate), calculated using equations of Nuttli and Herrmann (1981). A study of earthquake damage to underground structures that evaluated 107 cases in eight countries determined that significant damage occurred only at surface accelerations greater than 0.5 gravity. Only minor damage was observed in some cases at surface accelerations of 0.2 gravity to 0.5 gravity (McClure, 1981, p. 79-80). The predicted peak surface acceleration of 0.14 gravity is not expected to affect waste containment and isolation.

The acceleration estimate is calculated from an equation that predicts peak horizontal ground acceleration using earthquake magnitude and epicentral distance only (Nuttli and Herrmann, 1981). Thus, the value of 0.14 gravity estimated from this equation does not include any amplification or attenuation effects resulting from the near-surface, site-specific geology for which the elastic properties are not known in detail. However, the estimated ground motions are moderate and the near-surface geology at the site is not known to be unusual. Therefore, local effects are not expected to amplify the ground motion to levels that are unacceptable for design purposes.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. Based on the lack of seismicity within the Mississippi Salt Basin and the current understanding of basin tectonics, correlation of earthquakes with tectonic processes and features in the geologic setting is not possible. Hence for the purposes of this evaluation the presence or absence of young (Quaternary Age) faulting within the geologic setting is used to assess whether or not the frequency or occurrence or magnitude of earthquakes may increase relative to the baseline provided by the historical seismicity record. No seismically active tectonic structures within the geologic setting (Mississippi Salt Basin) are indicated by the historic earthquake data (Section 3.2.5.2). None of the historical earthquakes is known to be associated with surface fault rupture, and there is no evidence for recent tectonic activity in the vicinity of Richton Dome. The nearest location with a possible correlation between seismicity and tectonic structures is Clarke County, Mississippi, and nearby Melvin, Alabama, where a few earthquakes have occurred near the Pickins-Gilbertown Fault System. The Pickins-Gilbertown Fault System lies along the north boundary of the geologic setting. However, the accuracy of this correlation is uncertain because of epicenter uncertainties. There is no evidence to suggest that the frequency or magnitude of earthquakes may increase above historic levels.

The evidence indicates that the potentially adverse condition is not present.

(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.

Evaluation. Richton Dome is in an area of extremely low earthquake frequency (Section 3.2.5.2). No earthquake epicenters have been reported near Richton Dome (Figure 3-16). Neither of the nearest earthquakes, in 1975 about 75 kilometers (45 miles) south-southwest of the site, and in 1978 about 75 kilometers (45 miles) north-northeast of the site, occurred within the site's geologic setting (the Mississippi Salt Basin). Based on the distribution of earthquake epicenters in a region with a 480-kilometer (300-mile) radius (Figure 3-16), the site's geologic setting is characterized by less-frequent, lower-magnitude events than are representative of the region in which the setting is located.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. The evaluation of the potential for landslides, subsidence, or volcanic activity to create large surface-water impoundments considers (1) whether these tectonic processes are occurring, (2) the topographic character of the region, and (3) whether or not there is evidence that such impoundments were created in the past. First, as noted in Sections 3.2.5.3 and 3.2.5.4, the region has had no Quaternary igneous activity or tectonic subsidence. Landslides occur only infrequently in the region, and involve very small volumes of material. Thus, landslides are not expected to create impoundments of sufficient magnitude to affect regional ground-water flow patterns. Second, the region is characterized by gently rolling terrain dissected by wide, flat-bottomed valleys. Such terrain is not conducive to creation of large impoundments, particularly those with sufficient duration to influence regional ground-water flow patterns. Third, no large surface-water impoundments resulting from such natural processes exist in the region.

The evidence indicates that the potentially adverse condition is not present.

(6) Potential for tectonic deformations - such as uplift, subsidence, folding, or faulting - that could adversely affect the regional ground-water flow system.

Evaluation. As noted in Section 3.2.5, folding, faulting, and subsidence are not known to have occurred in the region during the Quaternary. Therefore, uplift is the only tectonic mechanism that needs to be evaluated for its effects on the regional ground-water flow system. Long-term regional uplift has occurred at the site at a rate of 0.1 meter per 1,000 years (0.03 foot per 1,000 years) (Section 3.2.5.4), and is considered too small to adversely affect the regional ground-water flow system over 10,000 years (see Sections 6.3.1.1 and 6.3.3). Faster rates of current uplift have been suggested from geodetic releveling surveys; however, these rates appear anomalous for the long term and may be in error (Section 3.2.5.4). The tectonic environment is not judged to have changed from its Quaternary characteristics, so the long-term uplift rates given above are considered to be the appropriate values for evaluating this potentially adverse condition.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.7.4 Analysis of 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.

Evaluation. The nature and rate of fault movement and other ground motion in the geologic setting are not likely to result in the loss of waste isolation. This assessment is based on the relative stability of the geologic setting during the Quaternary period as illustrated by lack of evidence for Quaternary fault movement; low frequency and magnitude of seismicity; slow, long-term uplift rates; and a lack of igneous activity. Discussion of these processes as they might affect the site's ability to isolate waste is presented under the analyses of favorable and potentially adverse conditions of this guideline. However, the net result of these processes is a slow rate of change within the geologic setting that should not adversely affect waste isolation.

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.7.5 Conclusion for the Qualifying Condition. The principal active tectonic process during the Quaternary Period has been slow, regional uplift, which is not disruptive.

Based on this record, future tectonic processes and events are not likely to be disruptive and thereby lead to radionuclide releases. No evidence of tectonic activity, other than uplift, has been recognized.

Evidence from the geologic setting suggests no igneous activity during the Quaternary Period. Salt-dome movement, if it is occurring, is at extremely slow, postdiapiric rates. The only active tectonic process is regional uplift that, on the basis of the record for the Quaternary Period, occurs at a rate of about 0.1 meter (0.03 foot) per 1,000 years. The site's geologic setting has experienced fewer and lower magnitude earthquakes than the surrounding region. No correlation has been found between earthquakes and known tectonic features in the geologic setting. A mean value for peak ground acceleration at the site of 0.14 gravity has been estimated using the historical earthquake data along with the geologic and tectonic characteristics of the setting. This acceleration is sufficiently low to permit effective mitigation measures to be incorporated into repository design, operation, and closure. Regional uplift, the only observed tectonic process, is not expected to adversely affect the regional ground-water flow system. The low topographic relief will not result in landslides large enough to cause large-scale surface-water impoundments in the site vicinity.

Therefore, based on the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.1.8 Human Interference and Natural Resources, Guideline 10 CFR 960.4-2-8-1

Site suitability concerning natural resources is manifested in two major concerns: one, repository operations may restrict access to important mineral deposits; and two, the presence of significant mineral resources at or near the site might attract future human activities which could compromise waste isolation. The first concern is discussed under the environmental (Sec. 6.2.1.6) and socioeconomic (Section 6.2.1.7) guidelines. The natural resources guideline deals with the latter concern. The aim of this guideline is to favor location of a repository away from natural resources which might encourage inadvertent human interference in the future.

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

6.3.1.8.1 Statement of Qualifying Condition.

> 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 specified in Section 960.4-1.

Evaluation Process. The available data on known and potential water, hydrocarbon, and mineral resources in the site vicinity are referenced. Potential for future exploration and development of resources that might occur near the repository site is assessed. An analysis of possible human interference activities is presented in Section 6.4.2.6. The results of this evaluation are summarized at the end of Section 6.3.1.

Relevant Data. Data on the human interference and natural resources at Richton Dome have been derived from numerous published sources and are summarized in Sections 3.2 and 3.3. Data summarized in Chapter 3 include the following topics:

- Hydrologic modeling (Sections 3.3.1 and 3.3.2)
- Dome size, shape, depth, and structure (Section 3.2.5), and stratigraphy and composition (Section 3.2.3)

- Exploration for both hydrocarbons and mineral resources (Section 3.2.8)

- Data for shallow salt domes in the interior salt basins (Section 3.2.8).

The Nuclear Regulatory Commission (NRC) has established a requirement for permanent site markers at a repository, and for wide dissemination of records about the repository and its contents (10 CFR Part 60). In its definition of unexpected processes and events, the NRC indicated that postclosure human interference at the site is not a credible scenario as long as permanent markers exist and that knowledge of a repository has been maintained. The Environmental Protection Agency (EPA) believes that markers, records, and other passive institutional controls should be effective in deterring systematic or persistent exploitation of a repository site, and that they can substantially reduce the likelihood of inadvertent intrusion as long as they endure and are understood (40 CFR Part 191). Further, EPA states that the agencies responsible for repository siting and development should assume that future intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities. The DOE has conducted feasibility studies of the types of physical monuments that might be used to mark a site (Berry, 1983, ONWI-474; Kaplan, 1982, ONWI-354; Human Interference Task Force, 1984, BMI/ONWI-537). Berry (1983) concludes that materials of sufficient durability exist to construct monuments that will last 10,000 years at all proposed repository sites. Other possible permanent markers include geochemical or magnetic anomalies placed in deliberate patterns over the controlled area. Additional studies examined ways to ensure that knowledge of a repository will be available to future generations through wide dissemination of records (Sebeok, 1984, BMI/ONWI-532; Tannenbaum, 1984, BMI/ONWI-535; Weitzberg, 1982, ONWI-379). The DOE has not yet selected a preferred option for site marking, but a conceptual design of a repository marker system will accompany the DOE's application for a license to construct and operate a repository (10 CFR 60.21). A final design is required for a license amendment to close a repository (10 CFR 60.51).

The influence of possible disruptive events and processes, operating beyond the repository controlled area, is discussed in Section 6.4.2.6.

Assumptions and Data Uncertainty. Exploration for resources at Richton Dome has been extensive; however, some residual uncertainty exists about the potential for unidentified hydrocarbon and mineral resources. This uncertainty is considered small because exploratory drilling has occurred without discovering resources, and very few shallow salt domes in the interior salt basins are known to have associated mineral or hydrocarbon resources (Section 3.2.8.1). Furthermore, because deposits of resources known to exist near shallow domes are very limited in areal extent and production (Section 3.2.8.1), it is assumed that unidentified hydrocarbon and mineral resources that might exist at Richton Dome would be similar to these known occurrences. Some uncertainty exists about the value of resources that occur or may be identified at Richton Dome. A reasonable assumption is made that the factors that affect the value of the resources (e.g., depth, ease of extraction, resource quality) are similar to resources at other shallow domes. The implications to waste isolation from inadvertent drilling are discussed in Section 6.4.2.6.2. Surface mining of sand and gravel in the shallow subsurface would not affect release rates and are not included in this analysis.

In an unsuccessful effort to identify economic sulfur deposits in the caprock of Richton Dome, 34 sulfur exploration wells were drilled from 1944 to 1945. While the status of seals in these boreholes is uncertain, sufficient records exist to know the depth and lithology penetrated by each hole. Only eight holes were drilled into salt, the maximum penetration into salt was 6.4 meters (21 feet), and the deepest hole (total depth of 567 meters or 1,862 feet) completed in the dome bottomed in caprock along the flank of the stock.

Potential influences of human activities on site hydrology, such as ground-water withdrawal or surface-water impoundment, have not been modeled to obtain quantitative estimates of the range of potential impacts on the existing ground-water flow system. Thus, some uncertainty exists about these actions on the containment and isolation of waste. However, a regional ground-water model (Section 3.3.2) exists and the type of influence can be adequately assessed.

Analysis. Analyses relevant to this guideline include comparisons of resources at the site with other resources in the geologic setting, examination of the site's drilling and mining history, and assessment of the impacts of foreseeable human activities on the groundwater flow system. Section 6.4.2.6 discusses the potential for human interference which could affect nuclear waste containment and isolation. The DOE recognizes the difficulty in speculating on the future exploration strategy that may be used in the long term for any commodity, regardless of the current evaluation of resource potential. Whatever the resource potential is perceived to be (now or in the future) for that period of the immediate future during which institutional controls, permanent markers, and records are maintained and enforced, the site will be protected from any deep drilling near enough to affect repository performance. During this period, such resources that do exist will not be exploited.

Beyond this future period, it should be noted that the potential for conditions adverse to repository performance, caused by inadvertent deep drilling for resources within the controlled area, can only occur after the institutional controls and the institutions enforcing them have ceased to exist, and all knowledge of the repository from records and permanent markers surrounding the site has disappeared; or, alternately, if the surviving records and permanent markers are ignored. Thus, a severe setback in the course of civilization and subsequent recovery is presumed to be required for this scenario of accidental drilling intrusion while seeking expected resources, to occur.

The time required for this scenario to completely develop (the institutional control period, the failure of civilization and its subsequent recovery to levels where it would be technically feasible to carry out drilling operations that could disturb the repository, and the initial exploitation of the larger resources outside the site vicinity) is probably longer than the minimum containment time of the repository.

6.3.1.8.2 Analysis of Favorable Conditions.

(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.

Evaluation. The presence of salt at shallow depths (Section 3.2.8) is sufficiently known to suggest that both the salt and the underground space that could be excavated in the salt stock might be commercially extractable resources during the foreseeable future. Exploratory drilling to date has detected only minor hydrocarbon shows; no commercially extractable hydrocarbon resources have been identified (Section 3.2.8.1). Ground water as a natural resource is present in the upper aquifer over the dome but this is not a unique location for the ground water in southern Mississippi and the dome area contains only a small fraction of the groundwater resources of the region.

Actual development of the dome's resources after repository closure is considered unlikely because the complex nature of the development would involve advanced planning, including field investigations and data reviews that would probably recognize the presence of the repository. Also, the site will be marked with a suitable monument, or set of monuments, as required by the NRC (10 CFR 60.51).

The evidence indicates that the favorable condition is not present.

(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.

Evaluation. The condition states that a favorable condition is found where water encountered along a probable radionuclide flow path is not considered to be of potential use for humans or for human activity.

Any fluids in the path from the repository to the edge of the salt stock, currently defined as the boundary of the accessible environment, will be saturated with salt; therefore, total dissolved solids (TDS) concentrations are much greater than 10,000 parts per million.

The evidence indicates that the favorable condition is present.

6.3.1.8.3 Analysis of Potentially Adverse Conditions.

(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.

Evaluation. Richton Dome is the largest of 35 shallow (i.e., having salt present above a depth of 610 meters or 2,000 feet) salt domes within the Mississippi Salt Basin (Section 3.2.8). Because of the dome's size and depth, it is an excellent candidate for underground storage. The relative purity of the salt (91 percent sodium chloride) also indicates that the dome may be a candidate for extraction of salt by either solution mining or conventional mining methods. Depending on the method of excavation, the space could be used to store or dispose of a wide variety of materials. Twenty-four domes within the interior salt basins have been used to store liquid propane gas and other petroleum products, and openings in salt domes are being considered for storage of compressed air (Section 3.2.8).

Because a similar storage facility could not be constructed within, nor salt extracted from, the sediments that make up the bulk of the geologic setting, the dome has greater value than average for these purposes. When compared with other shallow salt domes, the potential for storage or salt extraction at Richton Dome remains above average because of its large size.

Commercial hydrocarbon resources are not known to exist at Richton Dome. Milliken (1985) clearly demonstrates that petroleum is rarely associated with shallow (depth to salt less than 1,524 meters or 5,000 feet) salt domes of the interior salt basins and then only in small quantities. Instead, oil and gas are generally obtained from strata over and adjacent to deep (1,829 to 3,658 meters [6,000 to 12,000 feet]), salt-cored anticlines or arches.

Structural features in the vicinity of Richton Dome potentially favorable as hydrocarbon traps are the Tiger Field anticlinal structure and Glazier Dome. Both Richton and Glazier Domes have salt withdrawal basins and unwarped sediments along their flanks. No other significant local structural anomalies are believed to exist, based on extensive seismic surveys. Seven wildcat prospects have been found in the site vicinity that were considered worthy of drilling. None of these wildcat wells showed evidence of hydrocarbons (Section 3.2.8.1) indicating that the probability of finding hydrocarbon accumulations on the dome flanks is very low.

Given the patterns of oil and gas accumulations in the Mississippi Basin and the extensive history of exploration, the likelihood of discovering additional hydrocarbon resources at Richton Dome is considered very small.

The evidence indicates that the potentially adverse condition is present.

(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.

Evaluation. The presence of Richton Dome has been known since 1944 when the discovery well was drilled (Section 3.2.8). Data analysis performed during area characterization of the site showed no evidence of holes, shafts, or other excavations that penetrate the repository horizon. The relatively recent discovery of the dome and the reporting requirements for mineral exploration provide confidence that all penetrations of Richton Dome are known from records and reported data.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. Area characterization studies have not identified drilling that would affect waste isolation and containment. The potential that one or more borings may exist but have not yet been identified is considered low. Drilling for mineral resources at Richton Dome has included a total of 34 sulfur exploration (Section 3.2.8.2) and 32 petroleum exploration wells within 10 kilometers (6.2 miles) of the dome. Also within this area are an estimated 125 water wells and 2 fluid disposal wells.

As described in Section 6.3.1.8.1 (Evaluation Process), it is reasonable to assume that the sulfur exploration wells have not adversely affected the waste-containment characteristics of the site. The deepest sulfur exploration well to encounter the dome (567 meters [1,860 feet]) is drilled along the steeply dipping edge of the dome and bottoms in caprock without penetrating salt. Only eight sulfur wells enter salt, with a maximum reported penetration of 6.4 meters (21 feet). If the potential exists that the sulfur exploration wells have locally increased the flow of water through the caprock, then potential exists for dissolution at the upper surface of the salt stock. However, the increase in the rate of flow and circulation of undersaturated water is expected to be small and resulting dissolution on the top of the stock is not likely to appreciably alter conclusions about the potential impacts of dissolution (Section 6.3.1.6). The conditions of these wells have not yet been evaluated as described in BGI and LETCo (1983, ONWI-293, p. 2-17).

Three petroleum exploration wells are reported to have entered salt at the site (Section 3.2.8.1). Two of these wells penetrated salt on the sloping dome flanks below a depth of 2,135 meters (7,000 feet) (LETCo, 1982, ONWI-120, Vol. VII, pp. 12-32 through 12-35) far below the proposed repository depth of 640 meters (2,100 feet). The third well (Shell-Masonite 23-7, Section 23-T5N-R10W) apparently penetrated the northeastern dome flank, encountered salt and possibly caprock between depths of 634 and 890 meters (2,080 and 2,920 feet), and then passed through sediments before reentering salt below a depth of 2,135 meters (7,000 feet). This penetration of salt by Shell-Masonite 23-7 occurs near repository depth in the outermost edge of the 244-meter (800-foot) perimeter pillar. Analysis of the potential for enhanced dissolution along such boreholes (Sections 3.2.5.7 and 6.4.2.6) suggests that the boreholes will not affect waste containment and isolation in the future. Reported penetrations below 2,135 meters (7,000 feet) do not, and will not, impact waste isolation at the site.

The water wells are shallow (less than 366 meters [1,200 feet]) and are drilled into the Upper Aquifer (Section 3.3.2). The fluid injection wells are drilled into deeper confined saline aquifers, and are at least 4.8 kilometers (3 miles) from the dome flank.

The evidence indicates that the potentially adverse condition is not present.

(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.

Evaluation. The only significant concentration of any naturally occurring materials at Richton Dome is salt, which is widely available from other sources. Salt is widely produced from brining operations, conventional mining of salt domes and bedded salts, and evaporation ponding. Potential underground storage sites exist and are used in salt domes across the Gulf Coast. Underground storage sites exist in other rock types in a variety of locations as well. Richton Dome's potential usage as an underground storage facility is not a unique resource.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. The portions of the ground-water flow system that are important to waste isolation at Richton Dome are the pathways of possible fluid travel discussed in Section 6.3.1.1 for the salt stock. The potential for foreseeable human activities to adversely change portions of this flow system is deemed to be very low.

Most of the potential human activities described in the guideline would affect ground-water flow in sediments adjacent to the dome and are very unlikely to affect travel through the salt stock. The geohydrologic system adjacent to the dome consists of three aquifers, separated by confining units (Section 3.3.2). Ground-water withdrawal, extensive irrigation, and construction of large-scale surface-water impoundments might induce changes in fresh-water aquifers, but would not appreciably influence travel times or paths in the lower saline aquifers that flank the dome near the proposed repository depth. Fluid injection would be into the deep confined saline aquifers and could influence ground-water flow in the vicinity of the injection well, but is unlikely to modify geohydrologic conditions sufficiently to significantly change travel time in the aquifers, or within the dome.

As stated in a previous evaluation, Richton Dome is a suitable candidate for underground storage through the development of solution-mined (or constructed) caverns. However, the potential for such use in the postclosure period (after a repository has been constructed) is not considered a credible event. Such an operation would occur only within the boundary of the controlled area. Current plans call for marking this area with a variety of permanent monuments and other signs (e.g., a buried magnetic anomaly). Records of the repository will be widely disseminated with a request that they be copied and renewed on a regular basis by future generations. Given these precautions it is unlikely that knowledge of a repository's location and content will disappear.

Also, a society with the need for, and capability of, constructing a pumped storage (or related) facility would readily detect the presence of a repository. It is logical to assume that such technologically capable societies would follow procedures similar to those used today. This includes performing a series of exploratory surveys (e.g. geophysical soundings, test drilling) prior to expending large amounts of resources on an underground mining operation. Such exploratory surveys would readily detect the existence of a repository, even if all markers were somehow lost.

Finally, given the current trend towards increased use of shallow salt domes as storage sites for a variety of substances, a large base of knowledge is being developed which should warn future societies against the incautious penetration of any salt dome.

No military activities of a magnitude that could alter the hydrologic system (e.g., nuclear weapons testing) are conducted in the dome vicinity.

The evidence indicates that the potentially adverse condition is not present.

6.3.1.8.4 Analysis of Disqualifying Conditions.

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.

Evaluation. This disqualifying condition deals with past activities that have created significant pathways between the repository and the accessible environment. A significant pathway is here defined as a route created by an existing drill hole, excavation, or extraction activity along which radionuclides can migrate to the accessible environment in excess of allowable standards.

Previous exploratory drilling that encounters salt is limited to two petroleum exploration wells (north and northwest flank of the dome) that enter salt well below repository level (LETCo, 1982, ONWI-120, Vol. VII p. A-3-9), one petroleum exploration well (Shell-Masonite

23-7) that penetrated the flank of the salt or caprock on the north edge of the dome, and eight sulfur exploration wells that penetrate no more than 6.4 meters (21 feet) into salt (Section 6.3.1.8, Analysis of Potentially Adverse Conditions). One area characterization boring (MRIG-9) also has been drilled into the salt stock and penetrates 155 meters (508 feet) into salt, which is 244 meters (800 feet) above the proposed repository horizon. The one borehole, Shell-Masonite 23-7, that apparently penetrated the flank of the salt or caprock on the north edge of the dome did so at a depth of approximately 634 meters (2,080 feet) to 890 meters (2,920 feet) and then continued to a depth of 4,552 meters (14,930 feet). No subsurface mining or extraction activities have occurred at the site (Section 3.2.8.1, Hydrocarbons). Only limited uncertainties about the disqualifying condition remain because of the remote possibility of undetected boreholes, the marginal penetration in Shell-Masonite 23-7, and the condition of sulfur exploration wells drilled at the site. Relevant data for these boreholes are summarized in Table 6-10 and locations are shown in Figure 3-12. The possibility of unreported boreholes that penetrate deep into the salt stock is considered small on the basis of studies conducted during area characterization (Simcox and Wampler, 1982, ONWI-280).

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

> (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.

Evaluation. Development of water resources and the possible hydrocarbon resources in sediment adjacent to the salt stock should not affect isolation. Fresh-water resources are present above the stock and their development would not affect aquifers near the proposed repository depth (Section 6.3.1.8). Possible hydrocarbon resources, if present at all, would be much deeper than the proposed repository depth, and development would not affect the waste isolation characteristics of the salt. Directionally drilled wells are used to test for hydrocarbons trapped in sediment along the salt stock flank but are terminated when bottomed in salt.

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

6.3.1.8.5 Conclusion for Qualifying Condition. The site is located so that exploration or extraction of natural resources at the site is not likely to cause interference that would lead to radionuclide releases greater than those specified in the guideline.

Potential resources at the Richton Dome site are few. High-quality salt at shallow depths and the underground space that could be developed within the salt stock are recognized as resources. The potential for hydrocarbon resources adjacent to the site is considered speculative. The resources present at the site are neither scarce nor unique. Similar resources of comparable or greater value or potential are present both within the geologic setting and in other geologic settings.

Human activities have not resulted, and are not likely to result, in significant modifications to the existing conditions. Exploratory drilling for hydrocarbons has not been found to affect adversely the ability of the site to contain and isolate waste, and supports the observation that such resources are unlikely to be found at the site. Additional drilling into sediments adjacent to the dome to develop water or possible unidentified hydrocarbons should not affect waste isolation. Subsurface mining has not occurred at the site. Human activities are unlikely to modify the existing ground-water flow system.

Considering the use of permanent markers to identify the site as containing nuclear waste, and reasonable projections of resource, value, and scarcity, there is no compelling reason to develop the dome's resources in the foreseeable future. The complex nature of developing either salt or underground space resources would involve advanced planning and characterization that would probably identify the site as unsuitable for such development.

Table 6-10. Total Depth and Thickness of Salt Penetrated in Drill Holes at Richton Dome

Well Name[a]	Total Depth		Thickness of Salt Penetrated	
	meters	feet	meters	feet
Exploro Corp. #9 Masonite	222	730	1	4
Exploro Corp. #7 Masonite	221	725	4	13
Exploro Corp. #3 Masonite	221	728	1	2
Exploro Corp. #1 Masonite	258	846	2	5
Exploro Corp. #8 Masonite	230	755	2	5
Exploro Corp. #4 Masonite	232	761	0	1
Minisearch B-6 Ridgway	230	755	5	15
Minisearch B-8 Ridgway	234	769	6	21
DOE/Masonite (MRIG-9)[b]	389	1,275	155	508
Shell Masonite #1	3,954	12,969	ND[d]	
Shell Masonite #21-1	4,420	14,497	ND[e]	
Shell Masonite #23-7[c]	4,552	14,930	ND[f]	

(a) Locations of shallow wells are shown on Figure 3-12.

(b) Location of this well is shown on Figure 3-18.

(c) Penetrated dome margin salt or anhydrite sheath from 634 meters (2,080 feet) to 890 meters (2,920 feet) below ground surface.

(d) No data, well bottomed in salt.

(e) No data, well bottomed in salt.

(f) No data, well bottomed in anhydrite.

Source: Simcox and Wampler, 1982, ONWI-280; LETCo, 1982, ONWI-120, Vol. VI.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-11 presents a summary of the results of the evaluation and the findings for the postclosure Technical Guidelines not requiring site characterization.

6.3.2 Postclosure System Guideline 10 CFR 960.4-1

The postclosure System Guideline requires compliance with those EPA and NRC regulations that are intended to ensure that the health and safety of the public and the quality of the environment will be protected.

This section evaluates Richton Dome with regard to the postclosure System Guideline for performance of the natural and engineered barriers. The evaluation of the natural barriers (geologic setting) is made in context of the related Technical Guidelines, evaluated individually in Section 6.3.1, and the performance assessments of the engineered barriers presented in Section 6.4.2.

As the site has not been characterized, the complete data base needed for conclusive evaluation of this guideline is not available at this time. The present evaluations are preliminary and are for the purpose of selecting sites for further characterization. The likelihood of the site meeting the guideline is judged from the presently available information, using appropriate and technically conservative assumptions.

Following presentation of the qualifying condition in 6.3.2.1, the process used in its evaluation is described in 6.3.2.2. Performance of the engineered barrier system and the geologic setting are discussed in 6.3.2.2 and 6.3.2.3, respectively. Conclusions are provided in Section 6.3.2.4.

6.3.2.1 Statement of 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.

This postclosure System Guideline is one of the four System Guidelines. Its purpose is to ensure that a geologic repository will perform in accordance with applicable standards and regulations.

This guideline addresses the entire repository system, including the geologic setting and the engineered barriers. The repository consists of two systems. The engineered barrier system is made up of the various engineered features of a repository (waste package, including waste form, canister and overpack, backfill, and repository shaft seal) designed to retard the release of radioactive waste. The geologic system comprises the various natural barriers provided by the geology of the site (e.g., rock characteristics, hydrogeology, geochemistry). Geologic systems are found as they are, not engineered, so one candidate site can have distinct advantages over another. The suitability of a site for site characterization cannot be determined based on only one or two characteristics of the repository system such as waste package material or geochemistry. The overall suitability of the repository system depends on the interrelated performance and contribution of many factors.

The System Guideline for postclosure performance particularly addresses the need to ensure protection of public health and safety from radioactive waste materials for at least 10,000 years. It incorporates relevant parts of EPA and NRC regulations: (1) the EPA limits on release of radionuclides to the accessible environment (40 CFR Part 191), and (2) the NRC

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Geohydrology	960.4-2-1	6.3.1.1		
(a) 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.			Geohydrologic setting has been shown to favor repository performance in that estimated horizontal ground-water travel times through the salt stock perimeter pillar have a median value of 3.5 x 10^7 years, which greatly exceed 10,000 years. Projected hydrologic processes will not affect the ability to contain waste. Host rock has low hydraulic conductivities. Ground water with more than 10,000 ppm total dissolved solids is present along likely travel paths.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions.				
(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.			Pre-waste-emplacement ground-water travel times horizontally through the perimeter pillar from the disturbed zone always exceed 10,000 years for the likely condition. A median value of 3.5 x 10^7 years was reported for 1,000 realizations.	The evidence indicates that a favorable condition is present.
(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.			Quaternary hydrologic processes projected 100,000 years will not adversely affect the site's ability to isolate waste. Travel times horizontally through the salt stock perimeter pillar exceed 10,000 years for the likely condition. A median value of 3.5 x 10^7 years was reported for 1,000 realizations. Salt dissolution is not expected to be significant and will not affect the ability of the site to isolate waste.	The evidence indicates that a favorable condition is present.
(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.			The geohydrologic setting can be characterized and modeled with available technology and with reasonable certainty. The effort required to validate models is uncertain.	The evidence indicates that a favorable condition is not present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:	960.4-2-1	6.3.1.1	None of the following four subconditions is met.	The evidence indicates that a favorable condition is not present.
(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.			Hydraulic conductivity in the salt stock is extremely low. Hydraulic conductivity in the surrounding geohydrologic units range from 4.6×10^{-6} to 2.2 meters per day which is considered low to moderate.	The evidence indicates that a favorable condition is not present.
(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.			Hydraulic gradient in the Lower Claiborne unit is upward; in the Upper Claiborne the gradient is predominantly horizontal with a small upward component. Within the salt stock the modeled gradient is predominantly downward.	The evidence indicates that a favorable condition is not present.
(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.			Limited data exist at this time to determine whether the condition can be found.	The evidence indicates that a favorable condition is not present.
(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.			The salt through which radionuclides must travel has low permeability and a low porosity. Only salt exists between the repository and accessible environment.	The evidence indicates that a favorable condition is not present.
(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:			Richton Dome does not lie within the unsaturated zone.	Not applicable
(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.	960.4-2-1	6.3.1.1		

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.				
(c) Potentially Adverse Conditions.				
(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.			Although changes to the geohydrologic conditions will occur, they are not expected to significantly increase the transport of radionuclides to the accessible environment.	The evidence indicates that a potentially adverse condition is not present.
(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.			TDS concentrations range from 24,500 milligrams to 30,000 milligrams per liter along the most likely ground-water flow paths.	The evidence indicates that a potentially adverse condition is not present.
(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.			Limited folding and faulting occur within the Richton Dome area. Regional ground-water system can be and has been modeled in a relatively straightforward manner. Local models have not yet been verified.	The evidence indicates that a potentially adverse condition is present.
(d) 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.			Travel time calculations always (1,000 trials) exceed 10,000 years for the likely conditions. A median value of 3.5×10^7 years was reported from 1,000 realizations.	The evidence does not support a finding that the site is disqualified (Level 1).
Geochemistry	960.4-2-2	6.3.1.2		
(a) Qualifying Condition.				
The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation.			Salt domes are low in moisture content. Presence of methane in domal salt is indicative of a reducing environment. Assessments of	The evidence does not support a finding that the site is not likely

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site (Page 4 of 13)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
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.			the geochemical environment and waste package corrosion show that the system will contain radionuclides for time periods in excess of the requirements under expected conditions.	to meet qualifying condition (Level 3).
(b) <u>Favorable Conditions</u>.				
(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.			Salt dissolution estimated in Section 6.3.1.6 is not expected to be significant and is not expected to affect the ability of the site to isolate waste.	The evidence indicates that a favorable condition is present.
(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.			Reducing conditions will promote the precipitation of many redox-sensitive radionuclides; others may form insoluble sulfate and/or carbonate minerals. Radiocolloid formation is expected to be minimized by the destabilizing effects of brines. Deep basin brines contain low concentrations of low molecular weight organic acids, which are weak complexing agents. Radiolysis reactions may form additional organic species, which are not expected to possess significant complexation characteristics.	The evidence indicates that a favorable condition is present.
(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.	960.4-2-2	6.3.1.2	The halite and anhydrite of the host rock are stable in the expected repository environment. Thermal dehydration of the low amounts of clay present is not expected to diminish its sorptive capacity.	The evidence indicates that a favorable condition is present.
(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.			Waste packages are expected to remain intact for more than 10,000 years. Assuming waste package failure at 300 years, considerably less than 0.001 percent of the one-thousand year radionuclide inventory will be released.	The evidence indicates that a favorable condition is present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(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.			Clays, glauconite, and lignite will promote sorption along the expected flow path; however, insufficient evidence is available to quantify the decrease in peak cumulative release, which will be investigated further during detailed site characterization.	The evidence indicates that a favorable condition is not present.
(c) 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 expected repository performance could be compromised.			In the presence of limited volumes of thermally-migrating brines or unlimited volumes of low-magnesium intrusion brines, calculated waste package lifetime exceeds the requirements of 10 CFR 60.113.	The evidence indicates that a potentially adverse condition is not present.
(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.			Although small effects may occur, sorption and rock strength properties are expected to be largely unaltered.	The evidence indicates that a potentially adverse condition is not present.
(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.			The presence of reduced species in ground water and sedimentary strata suggests that reducing conditions exist in both the dome salt and adjacent sediments.	The evidence indicates that a potentially adverse condition is not present.
Rock Characteristics	960.4-2-3	6.3.1.3		
(a) 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.			The salt dome is sufficiently large to ensure isolation of waste. Salt has high thermal conductivity, high ductility, and a low coefficient of thermal expansion. Domal salt requires no engineering measures beyond reasonably available technology to ensure isolation. Waste-generated heat effects will not decrease isolation.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site (Page 6 of 13)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(b) Favorable Conditions.				
(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 salt dome is both sufficiently thick and laterally extensive to accommodate a repository.	The evidence indicates that a favorable condition is present.
(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.			Salt has high thermal conductivity. Salt has a low coefficient of thermal expansion. Salt is ductile, especially under pressure and at high temperatures.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions.				
(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.			No conditions are found that would require engineering measures beyond reasonably available technology.	The evidence indicates that a potentially adverse condition is not present.
(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.	960.4-2-3	6.3.1.3	Thermally induced fractures will occur only within the disturbed zone. No potential for hydration or dehydration occurs in salt domes. Brine migration will be minimal in the dome and should occur only close to the disturbed zone. There is potential for most of these phenomena to occur, however.	The evidence indicates that a potentially adverse condition is present.
(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.			Waste-generated heat effects will not significantly decrease the containment provided by the salt.	The evidence indicates that a potentially adverse condition is not present.
Climatic Changes	960.4-2-4	6.3.1.4		
(a) Qualifying Condition.				
The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than			The paleoclimatic record over the Quaternary Period suggests that no dramatic changes of climate occurred in the geologic setting.	The evidence does not support a finding that the site is not likely

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
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 the site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.			Projections of climatic patterns suggest that future climatic conditions will not be likely to lead to radionuclide releases.	to meet the qualifying condition (Level 3)
(b) <u>Favorable Conditions</u>.				
(1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.			The paleoclimatic record suggests no dramatic changes of climate will occur in the geologic setting that would affect the surface-water system.	The evidence indicates that a favorable condition is present.
(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period.	960.4-2-4	6.3.1.4	Studies of Quaternary climatic extremes suggest ground-water recharge equivalent to present Gulf Coast setting. Sea-level lowering at various times during the Quaternary Period is assumed to have affected surface-water systems but had minimal effect on the ground-water system.	The evidence indicates that a favorable condition is not present.
(c) <u>Potentially Adverse Conditions</u>.				
(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.			Emplacement will not be within the unsaturated zone.	The evidence indicates that a potentially adverse condition is not applicable.
(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.			Climatic-induced changes of hydraulic gradient in the near-surface aquifer would be small, and the water-bearing units at the repository levels would not be affected. Climatic changes do not affect hydraulic conductivity or effective porosity of geohydrologic units. The minimal climate-induced perturbations in ground-water flux anticipated will not significantly increase the transport of radionuclides to the accessible environment.	The evidence indicates that a potentially adverse condition is not present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
<u>Erosion</u>	960.4-2-5	6.3.1.5		
(a) <u>Qualifying Condition</u>.				
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.			Waste emplacement will be at a depth of 646 meters (2,120 feet). Quaternary erosion rate is estimated to be 0.12 meter (0.4 foot) per 1,000 years. The amount of rock and salt remaining after one million years is in excess of minimum emplacement depth. Nature and rates of erosional processes will not be likely to lead to radionuclide releases greater than those allowable.	The evidence does <u>not</u> support a finding that the site is not likely to meet the qualifying condition (Level 3).
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.				
(b) <u>Favorable Conditions</u>.	960.4-2-5	6.3.1.5		
(1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.			Waste will be emplaced at a depth of 646 meters (2,120 feet) below the overlying ground surface.	The evidence indicates that a favorable condition is present.
(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.			At the projected erosion rate of 0.12 meter (0.4 foot) per 1,000 years, 647 meters (2,116 feet) of overburden will remain after 10,000 years. This indicates the probability of radionuclide releases will not be increased due to erosional processes in 10,000 years.	The evidence indicates that a favorable condition is present.
(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.			At the projected erosion rate of 0.12 meter (0.4 foot) per 1,000 years, 1 to 122 meters (4 to 90 feet) of overburden, 6 to 65 meters (20 to 213 feet) of caprock and an average of 421 meters (1,380 feet) of salt stock will remain after one million years.	The evidence indicates that a favorable condition is present.
(c) <u>Potentially Adverse Conditions</u>.				
(1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.			Topographic relief is low and terrace deposits indicate alternating periods of deposition and incision throughout the Quaternary.	The evidence indicates that a potentially adverse condition is not present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site (Page 9 of 13)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(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.			The nature and rate of geomorphic processes during the Quaternary have resulted in an erosion rate of 0.12 meter (0.4 foot) per 1,000 years. This erosion rate projected over 10,000 years will not adversely affect the ability of the repository to isolate waste.	The evidence indicates that a potentially adverse condition is not present.
(d) 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.			Waste will be emplaced at a depth of 646 meters (2,120 feet).	The evidence does not support a finding that the site is disqualified (Level 1).
Dissolution	960.4-2-6	6.3.1.6		
(a) Qualifying Condition.				
The site shall be located such that any subsurface rock dissolution will 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.			Dissolution of the salt dome has occurred in the past as evidenced by the presence of a caprock. Relative to the 240-meter (787-foot) perimeter pillar planned for the repository, dissolution is not considered significant. Thus, dissolution will not lead to radionuclide release greater than those allowable under the requirements specified in Section 960.4-1.	The evidence does not support a finding that the site is not likely to meet the qualifying condition.
(b) Favorable Condition.				
No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.			Geologic evidence indicates that there was no significant dissolution during the Quaternary Period. The geologic and hydrologic setting over and near the dome has not been notably disrupted by Quaternary dissolution. The rate of Quaternary dissolution if projected for 10,000 years would not measurably affect the ability of the site to contain and isolate waste and, therefore, is anticipated to be insignificant in the context of the guideline.	The evidence indicates that a favorable condition is present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) 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.			Breccia pipes and dissolution cavities are not features reported in association with Gulf Coast salt domes. Evidence for past dissolution of the dome is present but not to the degree that it would create pathways from the underground facility which would lead to a loss of waste isolation.	The evidence indicates that a potentially adverse condition is present.
(d) Disqualifying Condition.	960.4-2-6	6.3.1.6	Dissolution of the salt stock is not expected to occur in 10,000 years. Relative to the 240-meter (787-foot) perimeter pillar planned for the repository, dissolution is not expected to cause hydraulic interconnection of the underground facility and the geohydrologic system.	
The site shall be disqualified 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.				The evidence does not support a finding that the site is disqualified (Level 1).
Tectonics	960.4-2-7	6.3.1.7		
(a) 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.			Future tectonic processes and events in the geologic setting are not likely be disruptive and thereby to lead to radionuclide releases. The principal tectonic process that has been observed is slow regional uplift, which is not disruptive. No evidence of other tectonic processes has been recognized.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
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.				
(b) 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.			There is no evidence of igneous activity during the Quaternary Period. The regional uplift rate measured for the Quaternary Period is 0.01 meter (0.03 foot) per 1,000 years. If continued into the future, this uplift rate is considered insufficient to lead to releases of radionuclides over the first 10,000 years after closure.	The evidence indicates that a favorable condition is present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
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Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) Potentially Adverse Conditions.				
(1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.	960.4-2-7	6.3.1.7	The geologic record of the Quaternary Period indicates that slow regional uplift is occurring. Salt dome movement, if it is occurring, is at post-diapiric rates of 0.01 meter (0.03 foot) per 1,000 years. There is no evidence to suggest that other tectonic processes have been active during the Quaternary Period.	The evidence indicates that a potentially adverse condition is present.
(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.			The predicted mean-value for peak ground acceleration at the site (0.14 gravity) is low enough to permit effective mitigation measures.	The evidence indicates that a potentially adverse condition is not present.
(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.			No correlation has been found between earthquakes and major tectonic features in the geologic setting. There is no evidence to suggest that the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.	The evidence indicates that a potentially adverse condition is not present.
(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.			The site has experienced less frequent and lower magnitude earthquakes than the surrounding region.	The evidence indicates that a potentially adverse condition is not present.
(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.			Low topographic relief will not produce landslides large enough to create large-scale surface-water impoundments. No potential for subsidence or volcanic activity has been identified that would create large-scale surface-water impoundments.	The evidence indicates that a potentially adverse condition is not present.
(6) Potential for tectonic deformations--such as uplift, subsidence, folding, or faulting--that could adversely affect the regional ground-water flow system.			The only active tectonic process is slow regional uplift that is unlikely to affect the regional ground-water flow system.	The evidence indicates that a potentially adverse condition is not present.
(d) 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 geologic setting is relatively stable, as illustrated by the nature and rate of Quaternary tectonic activity.	The evidence does not support a finding that the site is disqualified (Level 1).

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Human Interference/Natural Resources	960.4-2-8-1	6.3.1.8		
(a) Qualifying Condition.				
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 specified in Section 960.4-1.			Exploration of the site has not adversely affected the site's ability to contain nuclear waste. Considering the use of permanent markers to identify the site, the limited number of resources at the site, and the relative abundance of these resources in this and other geologic settings, there is no compelling reason to develop the dome's resources in the foreseeable future.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions.				
(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.			Salt could be extracted from the site and there is the potential for development of underground space.	The evidence indicates that a favorable condition is not present.
(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.			Any fluid in the path from repository to edge of salt stock consists of fully saturated brine.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions.				
(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.			Salt could be extracted from the site and there is the potential for development of underground space. Salt and potential underground space of comparable or greater value or commercial potential are present within this and other geologic settings.	The evidence indicates that a potentially adverse condition is present.
(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.			No subsurface mining has occurred at this site.	The evidence indicates that a potentially adverse condition is not present.

Table 6-11. Postclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
(Page 13 of 13)

Statement of Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(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.	960.4-2-8-1	6.3.1.8	Eight sulfur exploration wells have penetrated salt within the site, but only penetrate a maximum of 6.4 meters (21 feet) into salt. Three petroleum exploration wells drilled adjacent to the site enter salt below a depth of 2,135 meters (7,000 feet), well below the proposed repository depth of 646 meters (2,120 feet). One petroleum exploration well enters the salt flank or caprock at repository level. Available studies indicate that potential effects from these boreholes should not affect the isolation of the repository.	The evidence indicates that a potentially adverse condition is not present.
(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.			Resources present at the site are neither scarce nor unique; salt and underground storage sites are widely available.	The evidence indicates that a potentially adverse condition is not present.
(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.			Foreseeable human activities are not likely to affect the ground-water flow system adjacent to the dome and, therefore, are unlikely to affect waste isolation. Foreseeable human activities within the salt stock (e.g., underground pumped storage, injection of fluids, and military activities) would not occur based on permanent markers and exploration activities identifying incompatibility of the site with the activity.	The evidence indicates that a potentially adverse condition is not present.
(d) Disqualifying Conditions.				
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.			No subsurface mining has occurred at the site. One exploration well penetrates the salt or caprock at repository level.	The evidence does not support a finding that the site is disqualified (Level 1).
(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.			Development of water and potential hydrocarbon resources in adjacent sediments would not affect isolation in the site.	The evidence does not support a finding that the site is disqualified (Level 1).

Performance Objectives (10 CFR Part 60). These regulations provide standards for performance of the total repository system and for the engineered barriers including the following:

1. Containment of high-level waste (HLW) within the waste package is to be substantially complete for not less than 300 years after permanent closure (10 CFR 60.113(a)(1)(A)).

2. Release rate of radionuclides from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory calculated to be present at 1,000 years following permanent closure (10 CFR 60.113(a)(1)(B)).

3. Release rates from the repository system to the accessible environment for individual radionuclides are specified in 40 CFR Part 191.

Performance standards for the various aspects of the geologic setting are provided in the Technical Guidelines relating to the postclosure Systems Guideline. These address the stable physical attributes of the geologic setting that most influence its capability to contain and isolate radioactive wastes, and the more transient processes and events that could influence continued performance of the geologic setting for extended periods of time.

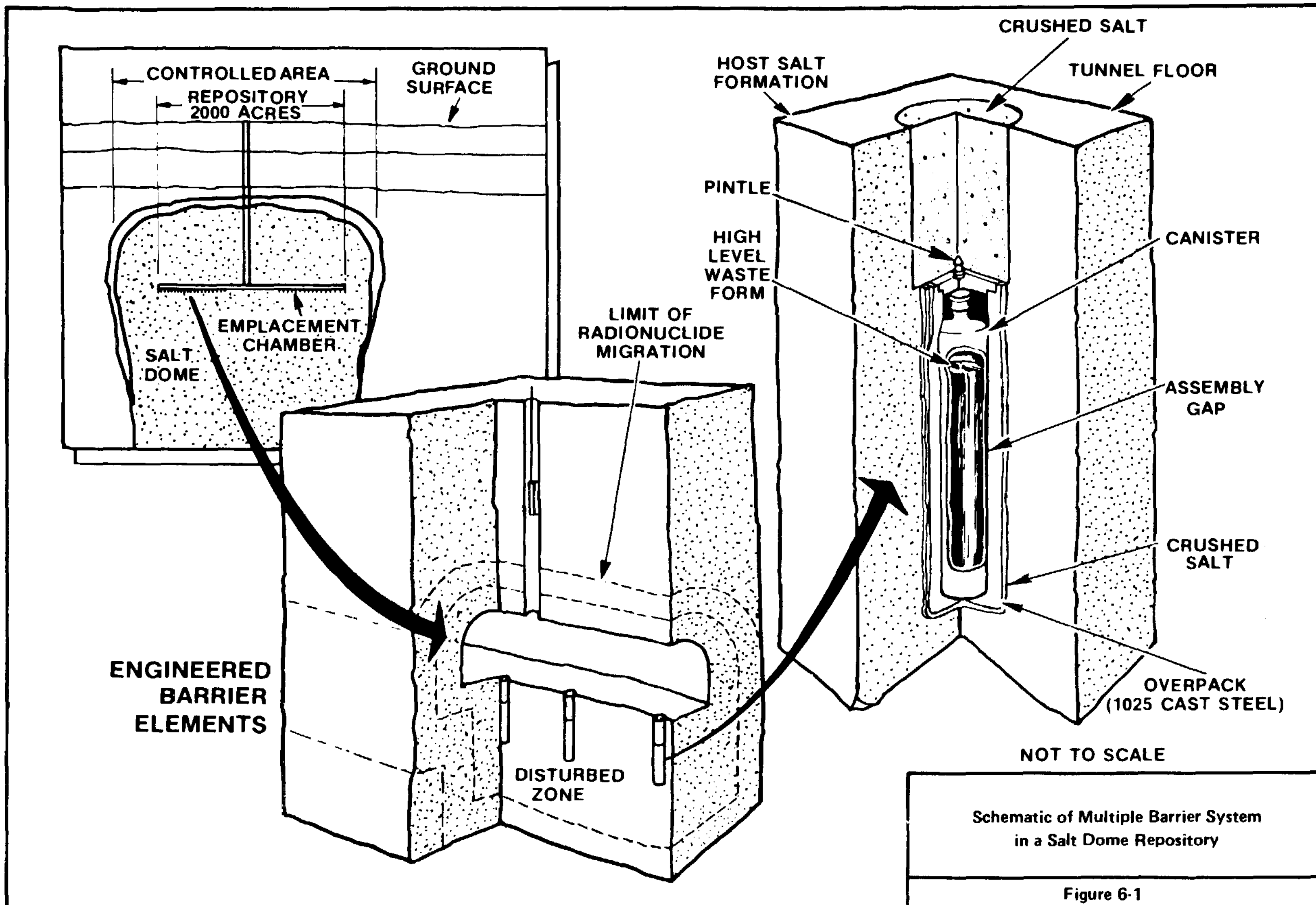
Evaluation Process. The evaluation of the system using the postclosure System Guideline is augmented by the use of the related Technical Guidelines addressing the geologic setting (Section 6.3.1). Performance assessments (Section 6.4.2) are used to investigate potential systems effects of selected conditions, processes, and events in the geologic setting and to evaluate elements of the engineered barrier system. Performance assessments also are used to evaluate compliance with 40 CFR Part 191 by calculating anticipated release rates of various radionuclides (Section 6.4.2.4).

The concept of a repository as a multiple barrier system is illustrated schematically in Figure 6-1. This evaluation process addresses the anticipated performance of each barrier individually and then assesses their collective contributions to overall repository performance. For site evaluation, primary emphasis is on the waste-isolation capabilities of the natural barriers. The engineered barriers are not relied upon to compensate for deficiencies that may be identified in the natural barriers.

Evaluation of the geologic setting is based on the findings with regard to the individual Technical Guidelines, as discussed in Section 6.3.1 and summarized in Table 6-11. The effect of individual guidelines on overall system performance is addressed by the presence of the favorable and potentially adverse conditions. The potentially adverse conditions are presumed to detract from expected system performance, but further evaluation, additional data, or the identification of compensating favorable conditions or mitigating factors may indicate that their effect on the expected system performance is acceptable.

The performance assessments of engineered barriers include several components. Waste package life is analyzed (Section 6.4.2.3.3) based on anticipated thermal conditions and on the quantities of brine expected to contact the package. Solubility of the waste form (Section 6.4.2.3.4), performance of shaft seals (Section 6.4.2.3.5), and combined performance of the engineered barrier system (Section 6.4.2.3.4) also are evaluated for potential compliance with the 10 CFR Part 60 criteria. In the absence of site-specific designs, the performance assessments address existing conceptual designs for the engineered barriers. These are considered to be adequate representations for this preliminary assessment.

The relevant data and assumptions used for the evaluations of individual Technical Guidelines and for the performance assessment are described in the related parts of Sections 6.3.1 and 6.4.2. The individual discussions also describe the uncertainties and limitations in the available data.



Schematic of Multiple Barrier System in a Salt Dome Repository

Figure 6-1

6.3.2.2 Performance of the Engineered Barrier System

The conceptual engineered barrier system designs are evaluated relative to the site conditions expected at Richton Dome. The two criteria addressed are (1) waste package life and (2) releases from the engineered barrier system.

Waste Package Lifetime. Waste package consists of the waste form, canister, and overpack materials. The waste package lifetime will be a function of thermal conditions, presence of brine, corrosion rates, solubilities, and external stresses. Corrosion rates will be determined by the overpack material properties, the ambient emplacement temperature, and the amount and chemistry of the contact fluids. Temperatures of the canister surface will be less than 300 C. In salt, only a small quantity of brine will migrate under the temperature field toward the waste package. External stress will be controlled by lithostatic pressures which are a function of depth. Preliminary assessment of the performance of the waste package is discussed in Section 6.4.2.3.3. The processes leading to package failure are described in Section 6.4.2.3.

Lifetimes were estimated for a range of fluid contact scenarios, including the very conservative assumption that brine flow quantities were unlimited. Results show that even in this extreme case, the waste package lifetime exceeds the 300- to 1,000-year requirement. When more realistic limits on brine flow quantities are used, the corrosion process becomes self-limiting and lifetimes can reasonably be expected to be much greater, i.e., greater than 10,000 years.

Engineered Barrier System. The engineered barrier system contains the waste package components plus the backfill and shaft seals. Performance assessments of various engineered subsystems are summarized in Table 6-12. The performance of the waste package under the constraints of limited brine inflow is expected to meet the radionuclide release specified in 10 CFR 60.113 for the engineered barrier system (Section 6.4.2.3). For this reason, the preliminary analyses reported in this document take no credit for radionuclide transport time through the remainder of the repository system. Such transport can reasonably be expected to reduce further the release of radionuclides from the engineered barrier system. These calculations are described and results compared with 10 CFR Part 60 release rate limits in Section 6.4.2.3.4.

As indicated by the waste package lifetime analysis, the "release rate" of radionuclides into the host rock is expected to be zero, because failure of the waste package is not likely. To analyze the effectiveness of the remainder of the engineered barrier system, analyses of performance limits have been performed assuming package containment failure at 300 years. The results of these calculations are given in Section 6.4.2.3.4 for CHLW and SFPWR at the NRC-mandated minimum package lifetime of 300 years. Assuming no thermal gradient threshold for brine migration, no brine consumed by chemical reaction beyond 300 years, and package failure at 300 years, these calculations indicate that cesium-137 will be the limiting radionuclide. With an interim waste form specification of 10^{-4} fractional release per year (ONWI, 1983, ONWI-462, p. 11) a package lifetime of 350 to 360 years would be required to meet the release rate limits for the engineered barrier system. However, waste package designs are expected to embody greater than 360-year performance lifetime.

Containment can be reasonably expected for features of the engineered barrier system other than the waste package (see Figure 6-1). These features would contribute to maintain release rates below those from the waste package alone. Hence, it appears highly likely that the 10 CFR Part 60 release limit requirements for the engineered barrier system would be met for a repository at Richton Dome.

6.3.2.3 Geologic Setting

This section summarizes evaluations of the eight postclosure Technical Guidelines in relation to overall assessment of the System Guideline, based on the more detailed discussions in Section 6.3.1. Results of these evaluations are summarized generally in Table 6-13. Richton Dome is considered likely to be qualified for site characterization on the basis of

Table 6-12. Summary of Performance Assessment Results

Cases Considered	Performance of Various Subsystems Related to Standards			
	Waste Package Lifetime	Engineered Subsystem	Geologic Setting	Total Repository System
Expected Conditions--				
Preemplacement	--	--	1. <10,000-year water travel time meets 1000-yr NRC requirement.	1. --
After Emplacement	2. <10,000-yr life--meets package life NRC requirements of 300-1000 years.	2. Zero release for at least first 10,000 years--meets NRC release requirement.	2. Zero release to AE[(a)] for 10,000 years + travel time.	2. Meets all requirements--including 40 CFR Part 191.
Performance Limits Cases Site Capability	3. Assumed zero years.	3. Waste form assumed not to restrict release.	3. Diffusion-like transport in host rock less than 20 m in 10,000 years.	3. Zero release to AE meets 40 CFR Part 191.
Engineered Subsystem (I)	4. Assumed 300 years.	4. Waste form assumed not to restrict release. NRC release requirement met for all except I-129, Cs-135, and Cs-137 based solely on brine flow and solubility constraints.	4. Diffusion-like transport in host rock less than 20 m in 10,000 years.	4. Zero release to AE meets 40 CFR Part 191. In fact, package releases[(b)] meet 40 CFR Part 191 if Cs-137 were not present.
Engineered Subsystem (II)	5. Assumed 300 years.	5. Waste form assumed 0.007 release. NRC release requirement met for all except Cs-137 based on brine flow & solubility limits.	5. Diffusion-like transport in host rock less than 20 m in 10,000 years.	5. Zero release to AE meets 40 CFR Part 191. In fact, package releases[(b)] meet 40 CFR Part 191 if Cs-137 were not present.
Engineered Subsystem (III)	6. Assumed 360 years.	6. Waste form assumed 10^{-4} ONWI specification release. NRC release requirement met.	6. Diffusion-like transport in host rock less than 20 m in 10,000 years.	6. Zero release to AE meets 40 CFR Part 191. In fact, package releases meet 40 CFR Part 191.
Engineered Subsystem (IV)	7. Assumed 490 years.	7. Waste form assumed not to restrict release. NRC release requirement met for all except I-129, Cs-135, and Cs-137.	7. Diffusion-like transport in host rock less than 20 m in 10,000 years.	7. Zero release to AE meets 40 CFR Part 191. Package releases are 40 CFR Part 191 quantities.
Engineered Subsystem (V)	8. Assumed 520 years.	8. Waste form assumed not to restrict release. NRC release requirement met for all except I-129, Cs-135, and Cs-137 based solely on brine flow and solubility constraints.	8. Diffusion-like transport in host rock less than 20 m in 10,000 years.	8. Zero release to AE meets 40 CFR Part 191. In fact, package releases meet 40 CFR Part 191.
Engineered Subsystem (VI)	9. Assumed 750 years (SFPWR) 760 years (CHLW)	9. Waste form assumed not to restrict release. NRC release requirement met for all except I-129 and Cs-135.	9. Diffusion-like transport in host rock less than 20 m in 10,000 years.	9. Zero release to AE meets 40 CFR Part 191. In fact, package releases meet 40 CFR Part 191.

(a) AE = Accessible environment.
(b) Package releases are defined as the quantities of radionuclides transported across the package boundary into the repository subsystem.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
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).	Geohydrology - 960.4-2-1 Geochemistry - 960.4-2-2 Rock Characteristics - 960.4-2-3 Climatic Changes - 960-4-2-4 Erosion - 960.4-2-5 Dissolution - 960.4-2-6 Tectonics - 960.4-2-7 Human Interference - 960.4-2-8	System Guideline: Preliminary assessments of the likely effectiveness of each barrier and the overall repository system in meeting guideline requirements are presented in Section 6.4. Radionuclide release limits specified in regulations 40 CFR Part 191 and 10 CFR 60.113 were used for comparison of results. Assessments included those for conditions expected at the site and a variety of postulated conditions to test limits of likely barrier and repository performance. The range of conditions analyzed and the performance estimated for each barrier and the repository system are summarized in Table 6-12. Results indicate that regulatory requirements with respect to barrier and repository release limits can be met at the Richton Dome site.	The evidence does not support a finding that the site is not likely to meet the qualifying condition.
	Geohydrology (Section 6.3.1.1)	The site is located such that the present and expected geohydrologic setting of the Richton Dome site is compatible with waste containment and isolation considering the processes and characteristics operating within the geologic setting. The ground-water travel time to the accessible environment (dome boundary) has been estimated to have a median value 3.5 x 10^7 years. This travel time estimate greatly exceeds 10,000 years. Hydrologic conditions present within the geologic media at the Richton Dome site could be affected by dissolution of, and ground-water travel time through, the salt stock. However, evaluations with respect to these processes conclude that projected	Technical Guidelines: The qualifying condition is present for the Richton Dome site.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site (Page 2 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		hydrologic conditions will not adversely affect the proposed site's ability to contain and isolate waste during the next 10,000 years. The data analysis for the Richton Dome region has indicated that the site can be adequately characterized and modeled. However, the favorable condition is not claimed because of the current sparsity of data and current lack of validated models. Horizontal hydraulic conductivity has been reported to range from 4.6×10^{-6} to 2.2 meters per day ($1.5x\ 10^{-5}$ to 7.2 feet per day) for the host rock and surrounding geologic media at the site. For the host rock, hydraulic conductivities are sufficiently low to inhibit the movement of radionuclides from the salt stock. Fluids along probable radionuclide flow paths to the accessible environment will constitute fully saturated brine. Such TDS fully saturated concentrations are in excess considered suitable for crop well of levels irrigation and human consumption.	
	Geochemistry (Section 6.3.1.2)	Domal salt possesses characteristics compatible with waste containment. Any releases of radionuclides from the waste package are expected to be retarded by geochemical conditions within the dome, and in surrounding units. Preliminary assessments indicate that the potential for salt dissolution to affect repository performance is negligible. Salt domes have a very low internal moisture content,	The qualifying condition with respect to geochemistry is present.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site (Page 3 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		and the presence of methane indicates that reducing conditions exist. These factors will inhibit corrosion of the waste package. Calculated rates of canister corrosion in the salt dome environment (under a variety of conditions) suggest waste package longevity far in excess of requirements. In the unlikely event of the breach of a waste package, calculations indicate that the iron-silica-dominated environment around the waste canisters will cause actinide elements to precipitate as stable compounds. A lack of oxidizing conditions within the dome also will inhibit solubility and movement of radionuclides. Halite and anhydrite, the primary constituents of the dome, have only weakly sorbing capabilities. However, the clay- and organic-rich sediments surrounding the dome are expected to provide a significant sorptive capacity should any releases occur. Sorption will be controlled somewhat by salinity levels in the surrounding ground water. This same salinity will tend to inhibit the formation of colloids in the particulate size range. Geochemical conditions in a repository are not expected to enhance radionuclide mobility over pre-waste-emplacement conditions. Neither will repository operations affect the overall ability of the dome to contain the waste. Decreases in salt strength due to brine accumulations or radiolysis will be very localized effects within a few centimeters of the waste package.	

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site
(Page 4 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		gamma radiolysis is not expected at the relatively low radiation flux levels at the waste canister surface.	
	Rock Characteristics (Section 6.3.1.3)	Richton salt dome is a massive body of halite. It is considered to be capable of accommodating the stresses expected from a repository, and to be compatible with the waste and engineered components. Richton Dome is sufficiently large to allow adequate lateral and vertical flexibility in placing the repository at a depth of 648 meters (2,125 feet). There are 22.2 square kilometers (8.5 square miles) at this depth, allowing a minimum of 244 meters (800 feet) of perimeter pillar around the respository workings. Domal salt has high thermal conductivity, high ductility, and a low coefficient of thermal expansion. Mining methods in salt domes are proven techniques and require no engineering measures beyond reasonably available technology. Heat and radiation effects are localized phenomena in the immediate vicinity of the repository, and will not decrease the salt dome's ability to isolate waste. Thermally induced fractures will occur only within the disturbed zone. Salt has the ductility to heal internal fractures. A lack of significant quantities of brine or hydrous mineral phases within the salt indicate that hydration/dehydration reactions will be negligible. Brine migration toward the waste canisters will affect rock	The qualifying condition is present for the Richton Dome.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site
(Page 5 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		strength only in the immediate vicinity of the repository (within the disturbed zone).	
	Climatic Changes (Section 6.3.1.4)	Richton Dome is located such that future climatic conditions will not likely lead to radionuclide releases greater than those allowable under the requirements specified in 10 CFR 960.4-1. The paleoenvironmental record indicates that the climate of the geologic setting has been stable over the last 125,000 years. Sea-level lowering at various times during the Quaternary Period altered surface-water systems but had little effect on deeper, confined flow. Projections of climatic patterns suggest that future climatic conditions will be similar to those that exist today. Therefore, changes in the hydrologic system, including hydraulic gradient and ground-water flux, will be minimal. Effective porosity and hydraulic conductivity will not change. These changes will not significantly increase the potential for transport of radionuclides to the environment.	The qualifying condition is present.
	Erosion (Section 6.3.1.5)	Richton Dome is located such that waste can be placed at sufficient depth so that erosional processes acting on the surface will not be likely to lead to radionuclide releases greater than those specified in 10 CFR 960.4-1. At Richton Dome waste will be emplaced at a depth of 648 meters (2,125 feet). The dome is situated	The qualifying condition is present.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site
(Page 6 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		in a geologic setting where the erosional processes that have been operating during the Quaternary have resulted in an erosion rate of 0.12 meter per 1,000 years (0.4 foot per 1,000 years). The amount of rock and salt remaining after one million years is in excess of the minimum emplacement depth. Topographic relief within geologic setting is low and the presence of Quaternary deposits in stream terraces suggests that sustained extreme erosion did not occur during the Quaternary Period. The Quaternary erosion rate projected over 10,000 years will not adversely affect the ability of the repository to isolate waste.	
	Dissolution (Section 6.3.1.6)	The extent of dissolution at Richton Dome estimated in the analysis for the Late Tertiary through the present is not considered significant. It is not likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. The evidence of dissolution used in the analyses of the favorable condition is the presence of a caprock. Reported anomalous salinities south of the dome appear to be related to lithologic changes in the Upper Aquifer, rather than to dome dissolution. The potentially adverse condition and disqualifying condition are not expected because dissolution projected to 10,000 years would result in little to no dissolution of the salt stock. Isolation relative to	The qualifying condition is present.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site
(Page 7 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		dissolution is enhanced by the large size of the salt dome and thickness of salt surrounding the planned underground facility. Thus, dissolution will not likely lead to creation of pathways that would interconnect the underground facility with the geohydrologic system.	
	Tectonics (Section 6.3.1.7)	The principal tectonic process during the Quaternary Period is slow, regional uplift, which is not disruptive. Based on this record, future tectonic processes and events are not likely to lead to radionuclide releases. No evidence of tectonic activity, beyond uplift, has been recognized. Evidence from the geologic setting suggests no igneous activity during the Quaternary Period. Salt dome movement, if it is occurring, is at extremely slow, post-diapiric rates. The only active tectonic process is regional uplift that, on the basis of the record for Quaternary Period, occurs at 0.1 meter (0.3 foot) per 1,000 years. The site has experienced fewer and lower magnitude earthquakes than the surrounding region. No correlation has been found between earthquakes and known tectonic features in the geologic setting. A ground acceleration of 0.14 gravity has been calculated from historical earthquake data. This acceleration will not affect repository performance. Regional uplift, the only observed tectonic process, will not affect the regional ground-water flow	The qualifying condition is present for Richton Dome.

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site
(Page 8 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		system. The low topographic relief will not result in landslides; therefore, large surface-water impoundments are not expected in the vicinity of the site.	
	Human Interference/ Natural Resources (Section 6.3.1.8)	The site is located so that exploration or extraction of natural resources at the site is not likely to give rise to interference activities that would lead to radionuclide releases greater than those specified in the guideline.	The qualifying condition is present at Richton Dome.
		Potential resources at the Richton Dome site are limited in number. High-quality salt at shallow depths and the underground space that could be developed within the salt stock are recognized as resources. The potential for hydrocarbon resources adjacent to the site is considered speculative because of the extensive testing of potentially favorable structures which has taken place. The resources present at the site are neither scarce nor unique. Similar resources of comparable or greater value or potential are present both within the geologic setting and in other geologic settings.	
		Human activities have not resulted and are not likely to result in significant modifications to the existing conditions. Exploratory drilling for hydrocarbons has not been found to adversely affect the ability of the site to contain and isolate waste, and tends to support the observation that such resources are unlikely to be found at the site. Additional drilling into	

Table 6-13. Postclosure System Guideline Considerations Requiring Site Characterization, Richton Dome Site (Page 9 of 9)

System Guideline 960.4-1(a)	Associated Technical Guidelines	Assessment Results	Findings
		sediments adjacent to the dome to develop water or possible unidentified hydrocarbons should not affect waste isolation. Subsurface mining has not occurred at the site. Human activities are unlikely to modify the existing ground-water flow system. Considering the use of permanent markers to identify the site as containing nuclear waste, and reasonable projections of resource, value, and scarcity, there is no compelling reason to develop the dome's resources in the foreseeable future. The complex nature of developing either salt or underground space resources would involve advanced planning and characterization that would probably identify the site as unsuitable for development.	

the eight postclosure Technical Guidelines relating to geologic setting. All of the qualifying conditions were found while none of the disqualifying conditions was found. Accordingly, the emphasis in this section is on presenting the balance of favorable and potentially adverse conditions that have been identified.

Evaluations of the Technical Guidelines presented in Section 6.3.1 represent qualitative assessment of the site's ability to successfully undergo characterization and meet 10 CFR Part 60 and 40 CFR Part 191 requirements. Various site-condition parameters embodied in each Technical Guideline have been used in the quantitative performance assessment to define projected release rates. Other site condition parameters do not directly factor into the performance assessment but have been used to establish the findings on the qualifying condition.

Geohydrology. The calculated ground-water travel times for Richton Dome greatly exceed 10,000 years. The domal salt has very low hydraulic conductivity, and projected hydrologic processes are not expected to reduce isolation capability. There are no potable water sources along flow paths to the accessible environment.

Richton Dome is considered particularly favorable because ground-water travel times from the repository horizontally through the perimeter pillar (the edge of the accessible environment) are estimated to have a median value of 3.5×10^7 years. Travel times in sedimentary units beyond the controlled area are variable.

Geochemistry. Richton Dome salt has a very low expected moisture content; the presence of methane gas in fluid inclusions within the salt indicates a reducing environment. Clay-rich units surrounding the dome are expected to have sorptive and reducing properties. No potentially adverse conditions were identified, but geochemical conditions are not known with confidence as site characterization has not been performed. The uncertainties regarding geochemistry do not reduce confidence in the isolation capabilities of the geologic setting, chiefly because of the very long ground-water travel times of any fluids within the host salt.

Rock Characteristics. The Richton Dome salt stock provides sufficient thickness and lateral extent for the underground facility. Domal salt, with generally homogeneous characteristics, is considered particularly well suited for construction of the underground facility and for accommodating the thermal, chemical, mechanical, and radiation stresses of radioactive waste isolation. Thermally induced fracturing of the salt may occur in the vicinity of the waste packages, and brine migration toward thermal centers will take place; however, these phenomena will have negligible effects on repository performance.

Climate Changes. Future climate conditions are expected to be reasonably predictable and within ranges recorded for the past 125,000 years. Sea-level lowering at various times during the Quaternary Period is assumed to have affected surface water systems, but had minimal effect on ground-water flow. These conditions, if renewed, are not likely to lead to increased radionuclide releases.

Erosion. The repository level is to be at a depth of 648 meters (2,125 feet) and overburden (including salt and caprock) is projected to remain in excess of the 200-meter (656-foot) minimum even after 1,000,000 years of erosion. The favorable conditions are found. No potentially adverse conditions are identified.

Dissolution. Although dissolution has occurred at Richton Dome in the past, present rates must be very slow or nonexistent and are not expected to lead to increased radionuclide releases. The potential for future dissolution is compensated for by the thickness of the perimeter salt pillar and the extensive salt thickness over the repository level. As a result, increased releases of radionuclides are not expected in the first 10,000 years after closure, even if dissolution rates are greater than those estimated.

Tectonics. Richton Dome is in a tectonically stable *geologic setting*. The only potentially adverse condition found is slow regional uplift that has been occurring over the Quaternary Period. However, evaluations of the geohydrology and erosion technical guidelines indicate that the projected uplift rates will not adversely affect ground-water movement or cause excessive erosion rates. As a result, the potentially adverse condition will not detract from overall system performance.

Human Interference. Although potential resources are present at Richton Dome and exploration has occurred in the surrounding area, previous activities are unlikely to have created pathways between the projected underground facility and the accessible environment. Future penetrations to create such pathways are considered unlikely, based on the use of permanent markers to identify the site, the limited resources present, and the abundance of such resources in this and other geologic settings.

6.3.2.4 Conclusion

The Richton Dome is found to meet the qualifying condition for the postclosure System Guideline, based on meeting all the qualifying conditions, evaluations of the related Technical Guidelines, performance assessments of the engineered barrier system, and calculations of anticipated radionuclide release rates. Richton Dome was found to have all the qualifying conditions in the postclosure Technical Guidelines and none of the disqualifying conditions. While some potentially adverse conditions are found, these would be compensated for by favorable conditions. Performance assessments, based on the present design concepts for the engineered barrier system, indicate that the 10 CFR Part 60 criteria would likely be met at Richton Dome. Anticipated radionuclide releases are calculated to comply with 40 CFR Part 191.

Therefore, on the basis of the above evaluation, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-13 presents a summary of postclosure System Guideline considerations requiring site characterization, the assessment results, and the findings.

6.3.3 Preclosure Technical Guideline 10 CFR 960.5-2

The Technical Guideline in this section addresses the characteristics, processes, and events that influence site suitability relative to the preclosure System Guidelines. The specific factors considered here include the surface conditions of the site, the host rock and surrounding strata, hydrology, and tectonics. The site is evaluated against these conditions in terms of its ability to accommodate the repository and its attendant activities, while ensuring the health and safety of personnel. These evaluations are preliminary, because results of site characterization will be needed to complete the supportive data base.

6.3.3.1 Surface Characteristics, Guideline 10 CFR 960.5-2-8

The preclosure guideline on surface characteristics is concerned with conditions that are important to the ease and cost of constructing, operating, and closing a repository. In sites that are prone to periodic flooding, are located in a rugged terrain, or have other adverse surface features, special measures may be necessary for repository construction, operation, and closure. The cost of repository construction, operation, and closure could rise to prohibitive levels if a large number of special measures were necessary for these phases. However, other features of the site--those that would significantly enhance waste isolation--could be more important than the higher costs associated with adverse surface characteristics.

This guideline includes a qualifying condition, two favorable conditions, and one potentially adverse condition for analysis. It does not have a disqualifying condition.

6.3.3.1.1 Statement of 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 construction, operation, and closure.

Evaluation Process. The analysis of this guideline classifies the terrain over the dome using U.S. Army Corps of Engineers standards and describes surface water systems in terms of drainage and flood hazards. An understanding of these systems is important in the design of repository surface facilities. The results of the evaluation are summarized at the end of Section 6.3.3.

Relevant Data. The following sections present the surface features and facility design information on which the guideline evaluations are based:

- Surface facilities (Section 5.1)
- Terrain (Section 3.2.2.1)
- Probable maximum flood (PMF) analysis (Section 3.3.1.3)
- Stratigraphy (Section 3.2.3)
- Drainage (Section 3.2.2.1, Figure 3-25)
- Hydrology (Section 3.3.1.1)
- Soils (Section 3.2.9).

Assumptions and Data Uncertainties. Uncertainties are associated with the estimate of the probable maximum flood (PMF) elevation for the Richton Dome site. The estimate was derived by ETC (1985b), using stream cross section area and configuration determined from existing U.S. Geological Survey topographic maps.

It is assumed that Fox Branch will be diverted and channeled around the surface facilities using currently available technology. It is also assumed that proposed grading and fill operations will raise the elevation of the site area, on which the surface facilities will be located, above the floodplain. These engineering measures should remove the potential for flooding of surface and underground facilities.

Analysis. The U.S. Army Corps of Engineers Topographic Laboratories (1980, pp. 5-6, 11) has classified surface configurations as follows:

- Plains - Slopes generally 3 to 12 percent, locally to 30 percent
- Hills - Slopes mostly 10 to 30 percent, locally to 45 percent and higher near mountains
- Mountains - Slopes generally 30 to 45 percent, over 60 percent in more rugged areas.

From the descriptions above and the topography shown in Figure 3-6 the area over the dome can be classified as plains.

The soils over Richton Dome are well drained. Small ponds and marshy areas may form in the area immediately following heavy rainfall. However, these conditions last for very short periods, due to drainage characteristics of the terrain. Soils appear to be acceptable for larger grading operations during repository construction. No unacceptable foundation conditions are expected based on the information on the near-surface soils in the site area (Section 3.2).

During an event equal to the estimated PMF, the headwaters of Fox Branch could cause flooding of a portion of the area proposed for surface facilities. During construction, Fox Branch will be diverted and channeled around the southeast corner of the surface facilities and the area will be filled to assure that surface facilities will remain above the flood elevation (Section 5.2.2.1).

6.3.3.1.2 Analysis of Favorable Conditions.

(1) Generally flat terrain.

Evaluation. As presented in the analysis above, the area over Richton Dome is classified as plains. Slopes have been estimated from USGS 7½ minute topographic maps and are generally flat (generally 3 to 4 percent, locally up to 10 percent).

The evidence indicates that the favorable condition is present.

(2) Generally well-drained terrain.

Evaluation. As presented above, the site is generally well drained. The potential for ponding during heavy rains will be considered during design and construction. Possible problems with flooding from Fox Branch will be avoided when its flow is diverted and the site is graded during construction.

The evidence indicates that the favorable condition is present.

6.3.3.1.3 Analysis of Potentially Adverse Condition.

Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of floodplains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.

Evaluation. As discussed in Section 3.3.1.3 the entire dome area lies above the 100-year floodplain. The PMF floodplain at Richton Dome (Figure 3-27) encroaches upon the geologic repository operations area and the repository surface facilities occupy a portion of the floodplain. However, the present surface facilities site will be modified by filling low-lying areas, by dike construction, or by stream diversion, to prevent flooding of surface and underground facilities. This can be accomplished by currently available technology. The site is close to the headwaters of Fox Branch. No modifications of the floodplain are planned, upstream or downstream from the site, that would affect potential flooding. Therefore, the existing surface characteristics that could lead to flooding will be corrected during repository construction. However, a stringent interpretation of current site conditions leads to the conclusion that the potentially adverse condition is present.

There are no existing or planned engineered surface-water impoundments in the vicinity of Richton Dome. There are also no surface characteristics that could lead to the failure of engineered components. Therefore, surface characteristics will not lead to failure of existing or proposed surface-water impoundments or failure of engineered components of the repository.

The evidence indicates that the potentially adverse condition is present.

6.3.3.1.4 Statement of Disqualifying Condition. This guideline has no disqualifying condition.

6.3.3.1.5 Conclusion for Qualifying Condition. Slopes calculated for the topography over Richton Dome fall into the classification of the terrain as generally flat. The area over the dome is also classified as generally well drained. Construction of surface facilities at Richton Dome will require filling, stream channel relocation, and other modifications. These engineering measures are considered reasonably available technology. The streams to be diverted are minor headwater tributaries. Planned occupancy and modification of the Fox Branch floodplain will not increase potential flood hazards. No existing or planned upstream or downstream surface-water impoundments were identified that could affect the site. Surface characteristics will not lead to failure of surface-water impoundments or failure of engineered components of the repository.

Therefore, on the basis of the above evaluation the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.3.2 Rock Characteristics, Guideline 10 CFR 960.5-2-9

The objective of the preclosure guideline on rock characteristics is to ensure that due consideration is given to those characteristics of the host rock that may affect (1) the ease and cost of repository construction, operation, and closure and (2) the safety of repository workers. Among those characteristics are the thickness and lateral extent of the host rock, geomechanical properties that are favorable for the maintenance of underground openings, and conditions that would allow the construction of shafts and the underground facility with reasonably available technology.

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

6.3.3.2.1 Statement of 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.

Evaluation Process. Each of the requirements in this guideline is analyzed in terms of the available data and information on the estimated projected size and shape of the repository and how the emplaced wastes will interact with the properties of the host rock during preclosure. To meet this guideline the dome must be sufficiently large to accommodate a repository and planned excavation in the salt must be sufficiently stable to ensure that the repository can be constructed, operated and closed safely. Results of this evaluation are summarized at the end of Section 6.3.3.

Relevant Data. Data used to evaluate this guideline have been derived from a variety of sources. Much of this information is summarized in Section 3.2, and a description of the proposed repository layout is given in Section 5.1. Occupational safety is discussed in Section 5.1.3. Relevant data presented in Chapter 3 include the following:

- Site-specific stratigraphy (Section 3.2.3.2)
- Dome geometry (Section 3.2.5.6)
- Presence of anomalous zones (Section 3.2.6)
- Strength and deformation tests (Section 3.2.6.1)
- Thermal properties (Section 3.2.6.2)
- Borehole studies (Section 3.2.3.2)
- Aqueous geochemistry of the caprock and salt stock (Section 3.2.7.4).

Additional information for Richton Dome not included in Chapter 3 is as follows:

- Pillar and room safety (Stearns-Roger Services Inc., 1981, ONWI-283, pp. 3-41)

- State-of-the-art mining techniques for salt (D'Appolonia Consulting Engineers, 1976, pp. 3-8 to 3-10)

- Estimates of construction difficulty and cost (Stearns-Roger Services Inc., 1981, ONWI-283; D'Appolonia Consulting Engineers, 1976).

Assumptions and Data Uncertainty. It has been assumed that the limited core tested is representative of the in situ rock at the site, and site stratigraphy is as indicated from present exploration (MRIG-9). An inherent weakness in the above assumption is the fact that the cores tested are obtained from a vertical borehole in an almost vertical geologic structure. Further site-specific laboratory and in situ information is required to quantify the spatial variability of soil and rock properties. However, the geomechanical data base for Richton Dome shows salt properties similar to those of other domes and salt-mining experiences indicate that Gulf Coast salt domes typically have fairly uniform composition and rock characteristics. The scale of the tested specimen will also affect geomechanical test results. As discussed in Section 3.2.6, the Richton Dome samples are believed to be representative of the rock mass but not without some degree of uncertainty. Large-scale in situ testing will be required to verify this assumption and to provide conservative geomechanical parameters for final repository design and construction.

Some uncertainty exists about the location and nature of the salt stock margin. Caprock has been reported to depths of 2,062 feet (629 meters) on the dome flank, and may sheath the entire upper portion of the salt stock. Anomalous conditions, such as pressurized gas and brine "pockets," and inclusions of sedimentary material may occur along the outer margins of the salt stock. Such features have been observed at the edges of other salt domes that have been mined (Section 3.2.6), but their presence at Richton Dome has not been confirmed. Interior anomalous zones are not the expected condition at Richton Dome; however, confirmation of this prediction must await detailed studies of the dome interior. In addition, limited uncertainty exists about room closure computations, but the design parameters are considered conservative (Pfeifle et al., 1983, ONWI-450). Due to a lack of empirical data, there is some uncertainty regarding the effect of heat on the deformation of the salt host rock, and how this will affect deformation and room closure rates. While the salt host rock appears to be relatively competent at ambient temperatures, there is a lack of data concerning the effects of heat on the deformation of the mine openings and how this will affect tunnel stability, particularly roof stability. It is expected that tunnels can be kept open by periodic scaling of the roof or floor to maintain required clearances, and that excessively difficult repository design and construction procedures will not be required.

If present, heterogeneities, discontinuities, and impurities may influence rock mass behavior and characteristics as discussed in Section 3.2.6 and, therefore, impact repository design and construction. However, salt-mining experience in the Gulf Coast indicates mitigation of the effects of these features is possible with available technology as discussed under items (2) and (5) of Section 6.3.3.2.3 and Section 6.3.3.2.4.

Analysis. Analyses that are relevant to this guideline include those related to dome configuration and geometry (Section 3.2.5.6), evaluations of the geomechanical properties and in situ stress conditions of the host rock (Section 3.2.6.1), geochemical characteristics of the salt and surrounding media (Section 3.2.7), and thermal properties of the caprock and salt (Section 3.2.6.2).

Geomechanical and thermal properties, and in situ conditions used in the evaluations, are based on laboratory test data for Richton Dome and field testing and mining experience from other Gulf Coast domes. In addition, the thermomechanical behavior of the rock mass, considering room closure rates (centerline-roof-to-floor) has been analyzed by Wagner (1985, ONWI-300). Analysis and design of underground facility configuration has been performed by Stearns-Roger Services Inc. (1981, ONWI-283).

6.3.3.2.2 Analysis of Favorable Conditions.

(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.

Evaluation. Section 5.1 presents the physical characteristics of a high-level radioactive waste repository in Richton Dome. Tables 5-1 and 5-3 give the required physical dimensions of the waste disposal areas and the expected volumes of different types of nuclear waste. At the proposed repository depth of 648 meters (2,125 feet), an area of 22.2 square kilometers (8.5 square miles) is available to construct and house a repository. Richton Dome also has several thousand feet of vertical extent. This significant thickness, despite the possible existence of anomalous zones, provides considerable vertical flexibility for the siting of underground workings. Section 3.2.6 suggests that anomalous zones may not be characteristic of interior domes such as Richton. However, if an anomalous zone were encountered and it was determined necessary to exclude it from the available repository area, it still would not significantly limit the lateral flexibility. To evaluate this, some fundamental assumptions are necessary to estimate the area of exclusion. For conservatism the length of the zone is chosen to be equal to the longest axis of the dome (7.5 kilometers [12 miles]) and the width of the zone of exclusion is chosen to be 153 meters (500 feet), which would include more than just the anomalous zone (Section 3.2.6). Hence the area of exclusion would be 1.15 square kilometers (0.44 square miles). The cross-sectional area of the dome at a depth of -610 meters (-2000 feet) MSL available (22.2 square kilometers [8.5 square miles]) less the area required for the repository (8.17 square kilometers [3.16 square miles]) equals the excess area of the Dome (14.0 square kilometers [5.42 square miles]). When compared with the estimate of area which might be excluded (1.15 square kilometers [0.44 square miles]) it is apparent that the effect of such a zone would not be significant in terms of limiting the lateral flexibility. Therefore, Richton Dome is sufficiently thick and laterally extensive to allow significant flexibility in selecting depth, configuration, and location of a subsurface repository facility.

The evidence indicates that the favorable condition is present.

(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.

Evaluation. Based on mining experience in other Gulf Coast salt domes, use of artificial supports, such as rock bolts, to aid in roof control in the Richton underground openings is expected to be minimal during initial excavation (SCC, 1984b, p. 5-6).

In existing domal salt mines, openings 20 meters (60 feet) and more in width generally stand unsupported. Occasional roof bolts and wire mesh are used to support loose slabs or large spans at mine tunnel intersections. In general, the closure that is measured is due to the slow creep of the salt into the excavation, resulting in heaving of the floor, sagging of the roof, and convergence of the walls. These movements are generally predictable and are routinely handled in the mining operation by scaling.

There is some uncertainty concerning the effect of heat on the underground tunnels and how this will affect reexcavation and support of the tunnels. Room-scale calculations performed by Wagner et al. (1985, BMI/ONWI-512, Figure 3.3), using a viscoelastic constitutive model, indicated that vertical closure along the roof-floor centerline would approach 0.35 meters (1.15 feet) in 5 years for 5.5 x 5.5-meter (18-foot) rooms in Richton Dome salt. During this time period, the temperature of the roof will have reached 75 C (167 F) and will not reach a maximum of 105 C (221 F) until 25 years have passed (Wagner et al., 1985 BMI/ONWI-512, Figure 3.2). Hence rooms and tunnels kept open for more than 5 years will experience larger amounts of closure and will have to be periodically remined and/or supported to maintain accessibility.

The effect of prolonged heating on the failure mechanism of salt tunnels is not well understood, because the empirical data base is limited. At Project Salt Vault (Bradshaw and McClain, 1971, ORNL-4555, pp. 210-214), the floor area in Rooms 1 and 4 uplifted very rapidly when the heaters were turned on, but this uplift slowed to a nearly constant rate. Similar behavior occurred when the heat input was increased by 40 percent. When the heaters were turned off, the recovery of the floor uplift amounted to about 16 percent in Room 1 and 11 percent in Room 4, indicating that the mechanism of floor lift was more complicated than simple thermal expansion of salt around the heaters and that creep was the dominant mechanism. In the same rooms, the accelerated sag of a 0.6-meter (2-foot)-thick bed of salt in the roof once the heaters were turned on required the whole experimental area to be roof bolted.

Convergence measurements made during the Avery Island heater tests (Van Sambeek et al., 1983, ONWI-190(5), Figures 33, 34, and 35) produced roof-floor closures of only 2.5 x 3.8 centimeters (1 x 1½ inches) after 1,000 days of heating, and no evidence of roof slabbing is reported. These results have limited applicability due to the fact that convergence was measured close to the pillars and not near the center of the rooms.

It may be concluded that, while thermomechanical calculations can reasonably predict the amount of room closure and far-field behavior due to creep in the salt host rock, they are not reliable in predicting the response of underground tunnels in the early stages of heating. There is also little field evidence to indicate what failure mechanisms are acting immediately around the mine openings when salt exacerbates any tendencies for slabbing and spalling to occur, but it is not known how serious an effect this may have on tunnel stability and support, mine maintenance costs, and personnel safety. In addition it is not possible to estimate support requirements for retrieval, which for this evaluation has been considered part of repository operation as defined in 10 CFR 960.2. It is for these reasons that this favorable condition is evaluated to be not present.

The evidence indicates that the favorable condition is not present.

6.3.3.2.3 Analysis of Potentially Adverse Conditions.

(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.

Evaluation. As discussed above for favorable condition (1), the salt at Richton Dome appears to provide more than adequate thickness and lateral extent for the underground facility. There is limited uncertainty concerning the shape and dimensions of the dome at depth and the presence of any anomalous zones. However, present information indicates that there is sufficient flexibility available for selecting the depth, configuration or location of the underground facility.

The evidence indicates that the potentially adverse condition is not present.

(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.

Evaluation. No in situ characteristics or conditions have been identified that require engineering measures beyond the state of the art in underground construction. It has been noted that gas or brine pockets may be encountered in the dome, requiring special construction measures that are discussed under item (5) of this section. However, such occurrences and measures are not atypical in the mining industry. In addition, shaft construction will use ground-freezing techniques in penetrating aquifers.

D'Appolonia Consulting Engineers (1981, ONWI-255) includes an Appendix which is a general review of shaft lining and sealing methods. It presents a detailed discussion of the advantages and disadvantages of freezing, dewatering, and grouting, including suggestions for mitigating adverse consequences when possible. It also reviews the experience base from sinking shafts through aquifers overlying evaporite deposits, and states that "the Saskatchewan and Boulby examples are of particular interest in demonstrating that shafts can be sealed to prevent downward seepage into salt deposits, even where relatively high permeabilities and ground water pressures are involved."

The use of ground-freezing technology for shaft sinking is a well understood and viable technique for sinking shafts through well consolidated or poorly consolidated ground that is partially or fully saturated with water. The process can be applied to soil or rocks that contain pore water or water in fractures. Ground-freezing methods have been used for 100 years, and are considered available technology. The freezing method appears to have minimal impact on mechanical properties, although clay partings may deform when frozen. If the freezing/thawing cycle results in increased permeability immediately adjacent to the shaft, the potential downward flow can be controlled with installation of a grout curtain or an impermeable keyway below the freeze region.

The evidence indicates that the potentially adverse condition is not present.

(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.

Evaluation. Some re-excavation of passageways and panels is anticipated to be necessary to maintain excavation geometry due to salt creep and roof slabbing. As discussed in Section 6.3.3.2.2(2), the effect of prolonged heating on the failure mechanism of salt tunnels is poorly understood because of the limited empirical data base. Consequently, it is not known whether salt creep and roof slabbing will have a serious effect on the maintenance costs of underground openings during repository operations and closure.

These adverse effects on repository operations can be mitigated to some extent by minimizing the amount of elapsed time between excavation, waste emplacement and backfilling of the rooms. However, extensive support may be required to maintain the main passageways in the heated host rock that must stay open. In addition, it is not possible to estimate support requirements for retrieval, which for this evaluation has been considered part of repository operation as defined in 10 CFR 960.2. It is for these reasons that this potentially adverse condition is evaluated to be present.

The evidence indicates that the potentially adverse condition is present.

(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.

Evaluation. The principal geomechanical factors that could influence waste retrieval in salt are (1) thermal decrepitation of rock adjacent to the canister, (2) brine migration towards the canister, (3) radiation effects on the mechanical behavior of the adjacent rock, and (4) creep around and induced stress on the overpack. Re-excavation of the storage rooms and location of waste canisters is assumed to be required for retrieval and, while costly, should not pose undue hazard or difficulties.

The potential of thermal decrepitation adjacent to the canister is minimal. The maximum design temperature in salt of 250 C (482 F) (Westinghouse Electric Corporation, 1983, ONWI-438, p. 54) is chosen to be below the thermal decrepitation temperature of rock salt. Laboratory testing of salt from the dome indicates the actual decrepitation temperature to be in excess of 500 C (932 F) (Lagedrost and Capps, 1983, ONWI-522 p. 17). There is no evidence to suggest that likely impurities in the salt in the vicinity of the waste packages would lower the temperature at which thermal decrepitation of the salt occurs to below 250 C (482 F). Moreover, the maximum salt temperature of approximately 250 C (482 F) will occur within less than 0.5 meters (1.6 feet) of the surface of the waste package for a period of less than 20 years, so that in the worst situation the effect of increased temperatures would be to disaggregate only a small volume of salt around the waste package.

The migration of brine towards the waste canister is a factor in corrosion of the waste overpack. However, the canister will be designed to resist this corrosion (e.g., Westinghouse Electric Corporation, 1983, ONWI-438, pp. 471-479) and remain structurally sound. Salt from Richton Dome contains very little brine (less than 0.5 volume percent); therefore, the quantities of brine migrating to the canisters is expected to be negligible. Hence the potential for difficulties in retrieval operations due to brine migration is considered minimal. Additionally, due to the relative purity of the domal salt, hydration and dehydration of mineral components is expected to be minimal. At the maximum salt design temperature of 250 C (482 F) and at the expected radiation levels, negligible amounts of new brines or chlorine gas will be generated, and they will not pose a threat to workers.

The potential for retrieval problems relating to radiation effects on the mechanical properties of salt is also considered minimal. Based on preliminary studies, the influence of radiation will be limited to the very near field (within a few feet of the canister) and the radiation effect on mechanical properties is minor (Bradshaw and McClain, 1971, ORNL-4555, p. 7-10). Retrieval of the canisters in the presence of radiation could pose additional operational difficulties.

Creep of the salt will seal the air gap between the canister and the salt host rock shortly after emplacement, permitting the buildup of induced stresses on the canister (Wilems et al., 1980, ONWI-203, pp. 48-50). The waste canister overpack is to be designed to resist those lateral stresses induced by thermal expansion and in situ stresses (Westinghouse Electric Corporation, 1983, ONWI-483, p. 54). However, the creep closure of the air gap will require overcoring of the canister, or removal of the waste form from the overpack, which potentially could pose some difficulty in retrieval, and would require special equipment and techniques (see Section 5.1). The degree of difficulty remains to be evaluated completely.

From the above discussion, it can be concluded that this potentially adverse condition exists because, although thermal decrepitation of salt adjacent to the waste and radiation effects on salt do not appear to adversely influence waste retrieval, the required overcoring of the waste canister, the removal of the waste from the in-place overpack, and the presence of radiation and any brines would pose safety hazards and difficulty in retrieval during repository operations.

The evidence indicates that the potentially adverse condition is present.

> (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.

Evaluation. A detailed discussion on the anomalous zones is given in Section 3.2.6. Anomalous zones which could significantly affect construction and isolation (e.g. gas outbursts or sedimentary in-layers) are not the expected condition for Richton Dome. However, the presence of any anomalous condition cannot be completely discounted without detailed study.

The presence of some small brine pockets in the dome interior must be anticipated, but such pockets are very likely to be isolated and not connected with aquifers outside the dome; hence, they pose a minimal hazard to personnel. Mining experience in the region indicates that gas pockets may be encountered during excavation (D'Appolonia Consulting Engineers, 1976, pp. 3-32 to 3-33). However, problems with gas typically occur in the peripheral areas of the dome that will be avoided in repository construction. Potential hazards to mine personnel from gas pocket blowouts can be greatly minimized by special ventilation, advance probing techniques, monitoring systems, elimination of mine systems that would ignite gases, design of facilities to avoid peripheral areas, and the design and construction of the facilities in accordance with Mine Safety and Health Administration (MSHA) Regulations for gassy mines (30 CFR 57.21). All of these safety measures are proven technology. Exploration will be employed to detect interior anomalous zones, and these zones can be either avoided or excavated with special measures and in accordance with standard mining practice and MSHA Regulations.

The evidence indicates that the potentially adverse condition is present.

6.3.3.2.4 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.

Evaluation. Potential hazards to personnel during repository construction, operation, and closure due to rock characteristics are those common to underground salt mining. They consist of gas pockets, excavation instability, brine pockets, and water inflow. As discussed above, such potential hazards are not the expected condition at Richton Dome. If found, they can readily be mitigated by proven mine safety and engineering practices.

Previous mining experience in the region indicates pockets of various gases may exist in Richton Dome (D'Appolonia Consulting Engineers, 1976, pp. 3-32 and 3-33). However, the actual size and extent of any gas pockets in the dome are unknown. Gas pockets most often occur in domal peripheral areas, but the repository perimeter pillar under consideration would avoid the Richton Dome periphery. In the Gulf Coast, large gas pockets have been encountered in most coastal salt domes. However, no such occurrences are known in two of the three interior domes (i.e., Grand Saline, Hockley) that have been mined. Gas pockets were encountered in peripheral areas of the Carey Mine of the Winnfield Dome (D'Appolonia Consulting Engineers, 1976, p. 3-33).

Stability of excavations and shafts is also a safety concern in underground facilities. Typically in domal salt mines, roof and pillar stability is related to the extraction ratio (the ratio of excavated area to the total mine area), the depth of excavation, the strength of the rock, and the presence of anomalous zones. The extraction ratio of approximately 20 percent for a repository (Stearns-Roger Services Inc., 1981, ONWI-283, p. 3-42), is considerably lower than the 35 to 60 percent extraction ratio of a typical safe and successful mining operation in evaporite materials (D'Appolonia Consulting Engineers, 1976, p. 3-16), thereby reducing the pillar loadings. This lower extraction ratio minimizes instability due to in situ and thermally-induced stresses. The strength of the domal rock salt appears to be typical of rock-salt formations presently being mined. Conceptual design of the repository pillars has employed safety factors of greater than two to minimize room and pillar stability hazards (Stearns-Roger Services Inc., 1981, ONWI-283, pp. 3-39 to 3-46).

Brine pockets and water inflow from aquifers can potentially pose a hazard in underground excavation. These chiefly are of concern in the periphery of the dome, although some smaller brine pockets may be found in the dome interior. The proposed design avoids peripheral areas. Measures will be undertaken during repository construction and operation to prevent water inflow along the shafts that penetrate water-bearing units (Parsons Brinckerhoff/PB-KBB, 1983, ONWI-497, pp. 38 to 40). At present there are no data that suggest the existence of large brine pockets in the Richton Dome that could pose a hazard to personnel.

The uncertainties related to the discussions in the previous paragraphs need to be addressed and acknowledged. For example, although drilling data indicate favorable conditions at the repository horizon, there is still a significant degree of uncertainty regarding the lateral variation that may exist in the site-specific area. Consequently, rock mass behavior relating to preclosure conditions cannot yet be predicted with certainty, but the design will provide for a range of conditions that might be needed. For example, the extent of joints and fractures in the rock mass will generally dictate the extent of rock reinforcement or support needed to ensure stable excavations. This extent may range from occasional short rock bolts to closely spaced, deep rock bolts, or even to rolled-steel roof supports at weak sections or intersections. This scale of increasing support needs is coincident with a scale of increasing time and costs needed to do the work, but represents conventional technology. Similarly, the potential for gas and brine pockets translates to a need for proven mine safety and engineering practices in advancing an excavation heading, such as by doing borehole probing ahead of the face, and by bringing up ample ventilation and dewatering capability behind the face. Again, current drilling data have not yet exposed any significant evidence of gas and brine pockets, but a level of uncertainty is still present.

These levels of uncertainty will be appreciably diminished by the at-depth testing planned in the exploratory shaft work described in Section 4.1.2, but the design nevertheless will contain provisions of reasonably available technology to meet any of the conditions of risk to health and safety discussed.

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

6.3.3.2.5 Conclusion for Qualifying Condition. *The site provides adequate thickness and lateral extent for the underground facility.* The salt at Richton Dome is clean and uniform. These are favorable conditions for construction and stability of underground openings. Hazards to personnel from construction, operation, and closure at this site would be typical of those encountered in existing underground salt mines in domes and can be mitigated by standard mining practices. Similarly, cost and ease of construction would be typical of existing underground salt mines in domes of the Gulf Interior Region. The clean and uniform composition and massive characteristics of the Richton Dome salt will require minimal artificial support for underground openings. The only maintenance expected is routine recutting in the access drifts to remedy room convergence. Construction operation and closure would use available technology. Difficulty of retrieval would be evaluated from site-specific in situ testing. Some difficulty is anticipated from creep-induced stresses on the canisters and container.

Difficulties in construction or operations, or undue health and safety concerns are not expected to be caused by structural or stratigraphic features at Richton Dome. The available data do not suggest that such features are present. Salt mining experience in the region has shown that brine or gas pockets are unlikely in these interior domes. Where present, such anomalies are most common in the periphery of the dome, an area that will be avoided in the proposed design.

Therefore, on the basis of the above evaluation, the evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition (Level 3).

6.3.3.3 Hydrology, Guideline 10 CFR 960.5-2-10

The preclosure Technical Guideline on hydrology is concerned with (1) the potential effects of ground water on the construction and sealing of shafts and other underground openings, including the repository iteself; (2) the potential for flooding of underground workings by surface water; and (3) the availability of water for repository construction and operation. Its objective is to ensure that the geohydrologic setting will be compatible with repository construction, operation, and closure; will not compromise the functions of shaft liners and seals; and will allow construction, operation, and closure to be achieved with reasonably available technology at reasonable cost.

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

6.3.3.3.1 <u>Statement of Qualifying Condition</u>.

> The site shall be located such that the geohydrologic setting of the site will (1) be compatible with those 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 of Section 960.5-1(a)(3) to be met.

<u>Evaluation Process</u>. Evaluation of this guideline is based on site stratigraphy and material properties, characteristics of regional and local geohydrologic units, topography and flooding potential, and water supply sources. Existing design concepts considered include repository site layout, offsite development, shaft construction methods, water supply requirements and components of repository construction costs. Conflicts between the natural setting and design requirements are analyzed. The results of this evaluation summarized at the end of Section 6.3.3.

<u>Relevant Data</u> Data used for the analysis of this guideline are presented in the sections below:

- Hydrology (Section 3.3.1.1)
- Stratigraphy (Section 3.2.3.2)
- Geohydrology (Section 3.3.2.1)
- Ground-Water Modeling (Section 3.3.2.2)
- Flooding (Section 3.3.1.3)
- Water Supply (Section 3.3.3)
- Repository Site Layout (Section 5.1)

- Repository Access Routes (Section 5.3.1)
- Repository Shaft Construction (Section 5.1.2.4).

Assumptions and Data Uncertainty. It is assumed that drill and blast methods will be used during repository shaft sinking because of the large diameters required (Section 5.1.2). Alternative shaft construction techniques, however, are possible. It is planned that ground water will be controlled during shaft construction by ground freezing, although other water control techniques could be considered. Surface-water drainages will be controlled by diversion around the proposed repository site or be raising surface elevations of the site.

Water supply for repository construction, operation, and closure activities has been determined assuming minimum water conservation to establish an upper bound on water requirements.

The specific location, layout, and dimensions of repository surface and subsurface facilities are based on preconceptual designs (Section 5.1.2).

Analysis. Analyses of this guideline with respect to surface-water conditions are presented in Section 6.3.3.1. The characteristics of water-bearing units above and around the dome were evaluated with regard to repository construction techniques and requirements for shaft liners and seals (through the period of repository closure) (Section 5.1). The shaft liner and sealing system will be required to resist both water and earth pressure to the depth of the top of salt. Cost-effective designs for such conditions have been previously employed in mines and reservoirs in Gulf Coast salt domes.

6.3.3.3.2 Analysis of Favorable Conditions.

(1) Absence of aquifers between the host rock and the land surface.

Evaluation. Aquifer units have been identified over and adjacent to proposed repository levels at Richton Dome. These units, in descending order from the ground surface, include the Upper Aquifer, Upper Claiborne, and Wilcox aquifer units. Water-transmitting characteristics of these units are discussed in Section 3.3.2.1.

The evidence indicates that the favorable condition is not present.

(2) Absence of surface-water systems that could potentially cause flooding of the repository.

Evaluation. The surface facilities are to be located on high ground that is drained by Fox Branch and a tributary to Linda Creek. These surface-water systems would not cause flooding of the repository. Additionally, construction is to include diverting and channeling Fox Branch around the southeast corner of the surface facilities. This will further assure protection of the repository from flooding. However, since the floodplain currently intersects the repository site, the favorable condition does not now exist.

The evidence indicates that the favorable condition is not present.

(3) Availability of the water required for repository construction, operation, and closure.

Evaluation. Adequate ground-water resources are available from aquifers within the geohydrologic system surrounding Richton Dome. The water required for repository construction, operation, and closure will be supplied from wells located on the flanks of Richton Dome.

The evidence indicates that the favorable condition is present.

6.3.3.3.3 Analysis of Potentially Adverse Condition.

> Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.

Evaluation. Although the water-bearing units over the dome are saturated, mitigating measures for these conditions would use reasonably available technology and are standard mining practices. Sinking the shaft will require ground freezing. Ground freezing has been in use by the mining industry for approximately 100 years.

The evidence indicates that the potentially adverse condition is not present.

6.3.3.3.4 Analysis of 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.

Evaluation. Saturated water-bearing units occur over Richton Dome. However, these conditions have been encountered and dealt with in mining operations for many years, including during the mining of salt domes. Technology available to mitigate these conditions during shaft drilling and construction includes ground freezing, dewatering and other accepted water control methods.

Therefore, the evidence does not support a finding that the site is disqualified (Level 1).

6.3.3.3.5 Conclusion for Qualifying Condition. The surface-water and ground-water systems are compatible with activities required for repository construction, operation, and closure, and will not compromise the intended function of the shaft liners and seals. The ease and cost of construction are discussed in Section 6.3.4.

There are water-bearing units present above and adjacent to the dome. However, mining technology is readily available to control these conditions when encountered. The planned surface facilities are to be located on high ground in a well-drained area where flooding is unlikely. Moreover, the present surface characteristics will be modified to mitigate the potential for flooding. Adequate water supplies for construction, operation and closure are available from aquifers within the geohydrologic setting; wells can be located away from competitive resources.

Therefore, on the basis of the above evaluation the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.3.4 Tectonics, Guideline 10 CFR 960.5-2-11

Tectonic processes during the preclosure period could require design features that protect the facilities, the repository workers, and the public. The objective of the preclosure guideline on tectonics is to provide a high degree of confidence that the selected site is not likely to be affected by tectonic events of such magnitude that unreasonable design features would be required.

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

6.3.3.4.1 Statement of 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.

Evaluation Process. Section 960.5-1(a)(3) states that repository siting, construction, operation, and closure shall be demonstrated to be 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. To determine whether the qualifying condition for Tectonics can be met, relevant data are evaluated to estimate the potential effects of tectonic events and processes. Some tectonic processes such as broad scale uplift, subsidence, or folding occur at rates that are too slow to affect preclosure activities. The short-term tectonic phenomena that occur on time scale such that they could affect repository construction, operation, and closure are limited to fault rupture (and any associated uplift or subsidence), earthquakes, and volcanism. If these have occurred in the Quaternary period, the analysis assumes they may reoccur, and estimates are made of maximum events. The results of this evaluation are summarized at the end of Section 6.3.3.

Relevant Data. The data base relevant to this evaluation is the same as that used in Section 6.3.1.7.

Relevant Data. Data on the tectonic framework of the region have been derived from numerous published sources and are summarized in Section 3.2.5. Supporting stratigraphic and structural data also have been acquired from completion records and geophysical logs of petroleum industry wells and interpretations of petroleum industry seismic profiles. The stratigraphy and structure of the area near the site were further evaluated by borings and surface mapping during area characterization. Tectonic processes and relevant physical properties are discussed as follows:

- Physiography (Section 3.2.2.1)
- Erosional Processes (Section 3.2.2.2)
- Faulting (Section 3.2.5.1)
- Seismicity (Section 3.2.5.2)
- Igneous Activity (Section 3.2.5.3)
- Uplift/Subsidence (Section 3.2.5.4)
- Folding (Section 3.2.5.5)
- Salt Dome Development and Geometry (Section 3.2.5.6)
- Thermal Properties (Section 3.2.6.2)
- Geomechanical Properties (Section 3.2.6.1)

Additionally, a study by McClure (1981) examined earthquake damage to underground structures for 107 cases in eight countries. These processes and their relation to tectonics are discussed below.

Assumption and Data Uncertainties. The geologic history and tectonic evolution of the region and its salt domes are known generally from extensive mineral resource exploration. Nonetheless, the character of the data at the Richton Dome site requires that several assumptions be made for this evaluation.

The geologic setting and tectonic setting for Richton Dome are taken to be the Mississippi Salt Basin, which is bounded by the Pickens-Gilbertown Fault Zone on the north, the Mobile Graben on the east, and the Wiggins uplift on the south. The Mississippi Salt Basin extends westward into eastern Louisiana, but the western edge of the geologic setting is taken to be approximately coincident with Jackson Dome. The bounding features, as well as more distant tectonic features, can affect the site only indirectly, such as by generating earthquakes felt at the site.

The rate of modern regional uplift is uncertain. Geodetic (releveling) data for the period from 1934 to 1969 suggest that short-term uplift may be occurring at a rate much greater than the long-term rate indicated for the entire Quaternary Period by the geologic data. As discussed in Section 3.2.5.4, the regional geomorphology shows the uplift rates calculated from the releveling data are not reasonable estimates for long-term rates. The discrepancy between short-term and long-term rates may result from systematic errors in the leveling surveys, or short-term variations in uplift rates. These data will be reevaluated during site characterization.

The analysis assumes that the historic seismicity record combined with the geologic and tectonic data are adequate to estimate large future earthquakes and to predict whether seismicity will affect the facility performance and safety during postclosure. The seismicity data are extremely useful indicators of the current tectonic environment, but cannot be used alone to establish the potential seismic hazard.

There is some uncertainty about the southern extent of the New Madrid fault zone. This analysis uses the current interpretation, from studies sponsored by the U.S. Geological Survey and the U.S. Nuclear Regulatory Commission, which places the closest approach of the fault zone about 400 kilometers (250 miles) north-northwest of the site. If further studies extend the zone southward, it would likely end at the front of the buried Ouachita Mountains about 240 kilometers (150 miles) distant, or pass about 190 kilometers (120 miles) from the site. No faulting hazard at the site is expected from the New Madrid fault zone.

Analysis. Evaluation of fault rupture hazards rests largely on determining if faults in the geologic setting are active, and on the locations of any such faults. First, the record of the Quaternary Period was evaluated to determine whether Quaternary-age rocks are faulted. Because no Quaternary faults were identified (Section 3.2.5.1), the next step evaluated current seismic activity to see if earthquake epicenters indicated any faults not apparent from the geologic data. Although a few earthquake epicenters may correlate with the Pickens-Gilbertown Fault Zone (Section 6.3.1.7.3[3]), there are no epicenters reported within the geologic setting (Mississippi Salt Basin), and no active faults are indicated in the setting by the historical seismicity record. The analysis indicates that seismicity cannot be associated at this time with individual tectonic features and should be considered as a property of the region.

The hazards from strong ground motion produced by earthquakes were evaluated using deteministic analyses to characterize both the geologic setting and the larger region in terms of maximum earthquake potential. The maximum earthquake that might occur in the geologic setting is estimated to be magnitude M_{bLg} 5.3 (intensity VI-VII) (Nuttli and Herrmann, 1978, p. 78), which could produce a mean-value peak acceleration of 0.14 gravity according to the equations of Nuttli and Herrmann (1981). Maximum earthquakes predicted for the New Madrid Seismic Zone and the Wichita-Ouachita Zone are magnitudes M_{bLg} 7.3 and 6.2, respectively with corresponding mean-value peak accelerations at the site of 0.02 and 0.03 gravity, respectively (Nuttli and Herrmann, 1981). However, shaking at the site from a New Madrid source earthquake is expected to contain more long-period motion than shaking from a maximum earthquake in the site's geologic setting. This long-period ground motion must also be considered in seismic design.

There has been no igneous activity in the region during the Quaternary Period (Section 3.2.5.3).

6.3.3.4.2 Analysis of 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.

Evaluation. This condition considers the relative cost of providing earthquake-resistant facilities. In general, structure can be engineered to withstand very high levels of shaking, but costs can become unreasonable as design levels increase. A review of nuclear power plant sites in the United States indicates that about 90 percent have been built for design levels of 0.20 gravity or less. Therefore, the DOE criterion is that a mean-value estimate for peak acceleration of 0.15 gravity, or less, is significantly less than generally allowable.

Several earthquake sources, both local and regional, were analyzed for their maximum ground motion effects at the Richton Dome site. The worst case was selected as the maximum earthquake. As indicated in Section 3.2.5.2 the maximum earthquake at the site is estimated to be magnitude M_{bLg} 5.3 (intensity VI-VII), with a predicted mean-value for peak ground acceleration of 0.14 gravity. Therefore, the favorable condition is present. A somewhat higher acceleration value is likely to be used for eventual design purposes to allow for uncertainties and to provide conservatism. For comparison, the safe shutdown earthquake (SSE) accelerations used for nuclear facilities in the region are as follows:

Grand Gulf, Mississippi	0.15 gravity (Mississippi Power and Light Company, 1972)
River Bend, Louisiana	0.1 gravity (Gulf States Utilities Company, 1973)
Waterford, Louisiana	0.1 gravity (Louisiana Power and Light Company, 1971)

The evidence indicates that the favorable condition is present.

6.3.3.4.3 Analysis of Potentially Adverse Conditions.

(1) Evidence of active faulting within the geologic setting.

Evaluation. Studies to date provide no geologic evidence of Quaternary active faulting and no association of known faults with recorded seismic events within the geologic setting (see Section 3.2.5.2). 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 Gulf Coastal area associated with growth faults by the Wiggins anticline, active growth faulting is not expected. The F-7 fault lies along the northwest flank of Richton Dome (Figure 3-15), but geologic data show this fault has not been active since Eocene time (about 50 million years ago) (Section 3.2.5.2).

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. Historically, earthquake intensity at the site probably has not exceeded MMI VI, slightly less than the intensity VI to VII (MMI) associated with the estimated maximum earthquake. In terms of peak acceleration, the site probably has not experienced or exceeded the 0.14 gravity value estimated for the maximum earthquake (Section 6.3.3.4.1). Many facilities and structures (including nuclear facilities) are designed to accommodate these and greater levels of shaking. A study of earthquake damage to underground structures that evaluated 107 cases in eight countries determined that significant damage occurred only at surface accelerations greater than 0.5 gravity. Only minor damage was observed in some cases at surface accelerations of 0.2 to 0.5 gravity (McClure, 1981, pp. 79-80). Therefore, the recurrence of surface accelerations less than 0.14 gravity is not expected to represent ground motion in excess of reasonable design limits. Although the mine-damage study includes local site-specific effects implicitly, the 0.14 gravity value does not include the potential for amplification or attenuation caused by soil-column effects. Analysis for these soil-column effects requires site-specific data (elastic properties) that are not yet available. However, the ground motions are moderate and the near-surface geology at the site is not known to be unusual, so the local effects are not expected to amplify the ground motion to levels that are unacceptable in the design.

Richton Dome has very low potential for induced seismicity. There are no known examples of induced seismicity in the geologic setting. The low rate of natural seismicity in the geologic setting, and in much of the Gulf Coast, suggests the absence of significant tectonism that could establish the conditions suitable for induced seismicity. Any large underground excavation can cause seismic events, if caving or subsidence are allowed to occur. Analysis for induced seismicity potential and design for excavation will require site-specific data on stress fields and rock properties.

The evidence indicates that the potentially adverse condition is not present.

(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.

Evaluation. Based on the lack of seismicity within the Mississippi Salt Basin and the current understanding of basin tectonics, correlation of earthquakes with tectonic processes and features in the geologic setting is not possible. Hence for the purposees of this evaluation the presence or absence of young (Quaternary Age) faulting within the geologic setting is used to assess whether or not the frequency of occurrence or magnitude of earthquakes may increase relative to the baseline provided by the historical seismicity record. The condition considers the likelihood that earthquakes during the preclosure period may be larger than those observed historically. Design earthquakes, which are unlikely and very low probability events, are considered under the favorable condition. The historical record over the past 80 to 100 years is taken as the most likely representation of seismicity over the next 50 years, unless there is contrary evidence for likely events from young faulting in the geologic setting.

In general, the observed seismicity in the region appears to be consistent with the region's structural and tectonic character. Within the geologic setting, historical earthquakes have not, with certainty, been correlated with faults. The nearest location with a possible correlation between seismicity and tectonic structure is Clark County, Mississippi, and nearby Melvin, Alabama, where a few earthquakes have occurred near the Pickens-Gilbertown Fault System. However, the accuracy of this correlation is uncertain because of epicenter uncertainties. The Pickens-Gilbertown Fault System lies along the north boundary of the geologic setting. None of the faults in the geologic setting is known to have moved in the Holocene (the past 10,000 years) (Section 3.2.5.1). Therefore, any movement on these faults is judged to be unlikely during the preclosure period.

The evidence indicates that the potentially adverse condition is not present.

6.3.3.4.4 Analysis of 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.

Evaluation. Characteristics of the site important to this assessment include a low rate of seismicity in the region, an estimated maximum earthquake at the site of magnitude M_{bLg} 5.3 (intensity VI-VII), and an estimated mean-value for peak ground acceleration of 0.14 gravity (Section 6.3.3.4.1). Furthermore, no evidence of Quaternary faulting or related ground displacements have been identified in the geologic setting.

Fault movements are not expected to occur at or near the site and thus would not affect either structures or openings. Surface structures can be designed to accommodate the expected levels of ground acceleration. Although data on the response of underground openings to earthquakes are limited, experience has shown that mines in rock have sustained only minor damage during events in which surface accelerations as great as 0.50 gravity were experienced (McClure, 1981, pp 79-80).

The evaluation indicates the nature and rates of ground motion expected at the site are not likely to require engineering measures beyond reasonably available technology to construct, operate, or close the exploratory shaft or repository.

The evidence does not support a finding that the site is disqualified (Level 1).

6.3.3.4.5 Conclusion for Qualifying Condition. Active tectonic processes would not lead to disruption of the repository function or require engineering measures beyond reasonably available technology for construction, operation, or closure. This finding is based on the absence of identified Quaternary fault displacements and volcanism, and the low level of historical seismicity (earthquakes are infrequent and low magnitude). No tectonic processes that would be disruptive and thereby lead to unallowable preclosure releases of radionuclides are expected.

Therefore, the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

Table 6-14 summarizes the preclosure Technical Guidelines requiring site characterization.

6.3.4 Preclosure System Guideline 10 CFR 960.5-1(a)(3)

The third preclosure system guideline is ease and cost of siting, construction, operation, and closure. It is ranked lowest because it does not relate directly to the health, safety, and welfare of the public or the quality of the environment. Here 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.

6.3.4.1 Qualifying Condition

6.3.4.1.1 Statement of 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.

Evaluation Process. A complete and detailed evaluation of the preclosure System Guideline will be performed when site characterization has been completed. For this environmental assessment, the available evidence has been used for a preliminary evaluation of the preclosure conditions at the site and the impacts that these conditions have on the ease and cost of repository siting, construction, operation, and closure. The results of this preliminary evaluation are used as the basis for a finding of whether or not the site is likely to meet the qualifying condition.

The siting guidelines list the following technical conditions as being pertinent to meeting the preclosure System Guideline:

- Surface characteristics of the site
- Characteristics of the host rock and surrounding strata
- Hydrology
- Tectonics.

For the preclosure System Guideline, an evaluation of these factors focuses upon two primary topics:

- Feasibility of the technical aspects of repository siting, construction, operation, and closure

- Reasonableness of the associated costs relative to other comparable siting options.

Table 6-14. Preclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site

Statement of Postclosure Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
Surface Characteristics	960.5-2-8	6.3.3.1		
(a) 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.			Terrain is generally flat and well-drained. The site will be modified to prevent flooding. There are no surface features that could lead to the failure of engineered components.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Condition.				
(1) Generally flat terrain.			Terrain is generally flat.	The evidence indicates that a favorable condition is present.
(2) Generally well-drained terrain.			Terrain is well-drained.	The evidence indicates that a favorable condition is present.
(c) 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.			The surface facilities site will be modified to prevent flooding. There is no existing or planned engineered surface-water impoundment in the vicinity of Richton Dome. The current floodplain crosses the repository boundary.	The evidence indicates that a potentially adverse condition is present.
Rock Characteristics	960.5-2-9	6.3.3.2		
(a) 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.			Richton Dome provides adequate thickness and lateral extent for the underground facility. The Richton Dome salt is clean and uniform, and is favorable for underground construction. Hazards to personnel would be typical of those in routine underground salt mining. Cost and ease of construction would be typical of existing underground salt mining.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) Favorable Conditions.				
(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.			Dome provides great vertical flexibility. Dome provides more than enough lateral extent.	The evidence indicates that a favorable condition is present.
(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.			Based on existing data, it is difficult to estimate the artificial support requirements for underground openings specially in the early stages of heating. Additionally, it is not possible to estimate the support requirements for retrieval, which for this evaluation has been considered part of repository operations as defined in 10 CFR 960.2.	The evidence indicates that a favorable condition is not present.

Table 6-14. Preclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
(Page 2 of 4)

Statement of Postclosure Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(c) <u>Potentially Adverse Conditions</u>.				
(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.	960.5-2-9	6.3.3.2	Dome provides adequate vertical flexibility. Dome provides more lateral area than used in design.	The evidence indicates that a potentially adverse condition is not present.
(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.			Shaft construction will use proven methods. Underground facility will be typical of existing salt mines.	The evidence indicates that a potentially adverse condition is not present.
(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.			No extensive maintenance is anticipated. Routine maintenance of excavations will be required. Additionally, it is not possible to estimate support requirements for retrieval, which is considered part of repository operations as defined in 10 CFR 960.2.	The evidence indicates that a potentially adverse condition is present.
(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.			Creep could lead to difficulty in retrieval. Also, retrieval of canisters in the presence of radiation could pose operational problems.	The evidence indicates that a potentially adverse condition is present.
(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.			Anomalous zones, found in some salt domes, may be present.	The evidence indicates that a potentially adverse condition is present.
(d) <u>Disqualifying Condition</u>.				
The site shall be <u>disqualified</u> 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.			Health and safety protection in domal salt mines can be provided with existing technology. Data do not suggest unique hazards at Richton Dome.	The evidence does <u>not</u> support a finding that the site is disqualified (Level 1).
Hydrology	960.5-2-10	6.3.3.3		
(a) <u>Qualifying Condition</u>.				
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(1)(3) to be met.			Surface-water and ground-water systems are compatible with activities required for construction, operation, and closure. The geohydrologic setting will not compromise the intended functions of the shaft liners and seals. Geohydrologic setting will permit the requirements for ease and cost of construction to be met.	The evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition (Level 3).

Table 6-14. Preclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site

Statement of Postclosure Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(b) Favorable Condition.	960.5-2-10	6.3.3.3		
(1) Absence of aquifers between the host rock and the land surface.			Aquifer units are present above and adjacent to the dome.	The evidence indicates that a favorable condition is not present.
(2) Absence of surface-water systems that could potentially cause flooding of the repository.			The surface facilities are located on high ground where flooding would be unlikely. However, the floodplain does cross the repository boundary.	The evidence indicates that a favorable condition is not present.
(3) Availability of the water required for repository construction, operation, and closure.			Adequate water supplies are available in shallow regional aquifers that are noncompetitive resources.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Condition.				
Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.			Ground-water aquifers over the dome are saturated. Required engineering measures are within currently available technology.	The evidence indicates that a potentially adverse condition is not present.
(d) 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.			Required engineering measures are within currently available technology.	The evidence does not support a finding that the site is disqualified (Level 1).
Tectonics	960.5-1-11	6.3.3.4		
(a) 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.			Faulting of Quaternary deposits has not occurred in the site geologic setting. No Quaternary igneous activity has occurred in the region. Historical seismicity is of low magnitude and frequency, indicating no adverse effects on construction, operation, or closure.	The evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).
(b) 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 that those generally allowable for the construction and operation of nuclear facilities.			Historical earthquakes in the geologic setting have occurred infrequently and generated intensities and/or ground accelerations well within values generally allowable.	The evidence indicates that a favorable condition is present.
(c) Potentially Adverse Conditions.				
(1) Evidence of active faulting within the geologic setting.			No historic surface ruptures or Quaternary fault movements are known to exist in the geologic setting.	The evidence indicates that a potentially adverse condition is not present.

Table 6-14. Preclosure Technical Guidelines Requiring Site Characterization, Richton Dome Site
(Page 4 of 4)

Statement of Postclosure Technical Guideline	Guideline Number	EA Section Number	Assessment Results	Findings
(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.	960.5-1-11	6.3.3.4	Historical earthquakes have not occurred within the site geologic setting.	The evidence indicates that a potentially adverse condition is not present.
(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.			Based on historical data and knowledge of regional tectonic elements, there is no reason to predict that the magnitude of future earthquakes in the geologic setting will be larger than in the past.	The evidence indicates that a potentially adverse condition is not present.
(3) 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.			Frequency of earthquakes and level of estimated peak ground acceleration are low. No evidence of Quaternary faulting is found in the geologic setting.	The evidence does not support a finding that the site is disqualified (Level 1).

Relevant Data. Relevant information with respect to Richton Dome is discussed under:

- Repository conceptual designs (Section 5.1)
- Geologic and hydrologic conditions (Sections 3.2 and 3.3)
- Site characterization activities (Section 4.1.1)
- Assessment of the Technical Guidelines pertinent to this preclosure System Guideline (Section 6.3.3), including
  - 960.5-2-8 Surface Characteristics
  - 960.5-2-9 Rock Characteristics
  - 960.5-2-10 Hydrology
  - 960.5-2-11 Tectonics.

Assumptions and Data Uncertainty. The level of site-specific data presently available has only allowed the iterative engineering process to proceed from a feasibility level to a conceptual level of design. Data from future site characterization activities are required before site-specific designs for the construction, operation, and closure of a nuclear waste repository can be finalized. Data uncertainty related to site characteristics is discussed as part of the evaluation of the pertinent Technical Guidelines listed in Section 6.3.4.1 and 6.3.4.2. However, the major assumptions underlying the engineering work performed thus far are as follows:

1. Soil conditions are adequate for building foundations and shaft sinking.

2. Ground-water inflow can be controlled during shaft construction through the use of conventional shaft sinking techniques.

3. Nongassy subsurface conditions have been assumed during underground operations; however, gassy mine conditions can be accommodated through the use of additional design features.

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 Department's annual evaluation of the adequacy of the one 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. Thus, the evaluation approach of this preclosure System Guideline includes a combination of qualitative and quantitative analyses.

A determination of the applicable Federal, State, and local permit requirements for repository siting, construction, operation, and decommissioning has not been made. Therefore, they have not been specifically considered in the repository cost estimates. The States do not appear to have identical permitting procedures, and therefore the possible cost impact of these permitting procedure differences cannot be quantified. However, the repository concepts, as well as their associated costs, do reflect anticipated design requirements which will be incorporated into the repository siting, construction, operation, and decommissioning activities in order to comply with the applicable environmental requirements.

Analysis. In order to reach a finding on the preclosure System Guideline, an evaluation was made in the context of the group of Technical Guidelines and the available evidence related to the System Guideline. Since the preclosure System Guideline does not have a disqualifying condition, the basis for the evaluation is the likelihood of meeting the qualifying condition for this guideline.

Three of the pertinent Technical Guidelines (Rock Characteristics, Hydrology, and Tectonics) have a disqualifying condition. These disqualifying conditions were examined in Sections 6.2 and 6.3 and a conclusion was reached that the available evidence did not support a finding that the site was disqualified. In addition, all four of the relevant Technical Guidelines have a qualifying condition. These qualifying conditions were examined in Sections 6.2 and 6.3 and a conclusion was reached that the available evidence does not support a finding that the site is not likely to meet the qualifying condition. Table 6-15 is a summary of the findings of the Technical Guidelines that are relevant to the preclosure System Guideline. This table includes a summary discussion of the favorable and potentially adverse conditions for the pertinent guidelines. The results of this table provide a reasonable basis for determining the technical feasibility and reasonableness of the associated costs for repository siting, construction, operation, and decommissioning. The discussion of retrievability in Chapter 5 shows that the retrievability is believed to be technically feasible. A possible retrieval method includes performing the following steps:

- Reexcavation of drifts which can be initiated after locating the drifts using in situ markers
- Reexcavation of the drifts, requiring proof-of-principle demonstration prior to license application
- Location of the waste packages utilizing magnetometers and other detectors
- Overcoring of the salt surrounding the waste package with conventional drilling equipment, and removal of the core and salt.

Other methods will be considered prior to selecting a design concept.

Although the system guideline does not directly address retrievability, it is believed that retrievability should be considered here, and that retrievability is or will be shown to be technically feasible with available technology.

6.3.4.1.2 Conclusion for Qualifying Condition. Prior repository feasibility designs together with continuing conceptual design efforts provide a basis for stating that the technology currently exists to design, construct, safely operate, and eventually decommission the structures, systems, equipment, and components if the nuclear waste repository were to be constructed at this site. In addition, these engineering design efforts have not identified any issues that could prevent repository siting, construction, operation, and closure from being in compliance with the applicable Federal, State, and local regulations.

The estimated total life-cycle cost for a repository located in either bedded or dome salt is $8.5 billion (1984 dollars). This includes costs for development and evaluation ($1.8 billion), construction ($1.6 billion), operation ($4.9 billion), and decommissioning ($0.2 billion). 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 disposal rooms and corridors. The operations estimate includes costs for the construction of the remainder of the underground facilities, the emplacement of the waste underground, and caretaker and backfilling activities. The decommissioning estimate includes costs for shaft sealing and the decontamination and dismantling of the surface facilities. These costs are discussed further in Chapter 7.4.

Therefore, on the basis of the above evaluation the evidence does not support a finding that the site is not likely to meet the qualifying condition (Level 3).

6.3.5 Conclusion Regarding Suitability of the Site for Site Characterization

On the basis of the findings stated in the above discussion of individual guidelines and made in accordance with Appendix III of the siting guidelines, it is concluded that the evidence does not support a finding that the site is disqualified, and does not support a finding

Table 6-15. Preclosure System Guideline Requiring Site Characterization, Richton Dome Site

System Guideline 960.5-1(a)(3) Ease and Cost of Construction, Operation, and Closure	Associated Technical Guidelines	Assessment Results	Finding
Ease and Cost of Construction, Operation, and Closure. Repository 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.	Surface Characteristics 960.5-2-8	Slopes calculated for the topography over Richton Dome allow classification of the terrain as generally flat. The area over the dome is also classified as generally well drained. Construction of surface facilities at Richton Dome will require filling, stream channel relocation, and other modifications. These engineering measures are considered reasonably available technology. Planned occupancy and modification of the Fox Branch floodplain will not increase potential flood hazards. No existing or planned upstream or downstream surface-water impoundments were identified that could affect the site. Surface characteristics will not lead to failure of surface water impoundments or failure of engineered components of the repository.	The evidence does <u>not</u> support a finding that the site is <u>not</u> likely to meet the qualifying condition.
	Rock Characteristics 960.5-2-9	The site provides adequate thickness and lateral extent for the underground facility. The salt at Richton Dome is clean and uniform. Hazards to personnel from construction, operation, and closure at this site would be typical of those encountered in existing underground salt mines and can be mitigated by standard mining practices. Cost and ease of construction would be typical of existing underground salt mines in domes of the Gulf	

Table 6-15. Preclosure System Guideline Requiring Site Characterization, Richton Dome Site
(Page 2 of 3)

System Guideline 960.5-1(a)(3) Ease and Cost of Construction, Operation, and Closure	Associated Technical Guidelines	Assessment Results	Finding
	Rock Characteristics 960.5-2-9 (continued)	Coast. The Richton Dome salt will require minimal artificial support for underground openings. The only maintenance expected is routine recutting in the access drifts to remedy room-convergence. Construction, operation, and closure would use available technology. Difficulty of retrieval would be evaluated from site-specific in situ testing. Some difficulty is anticipated from creep-induced stresses on the canisters and overpack.	
	Hydrology 960.5-2-10	The surface-water and ground-water systems are compatible with activities required for repository construction, operation, and closure and will not compromise the intended function of the shaft liners and seals. Potential for flooding presently exists, but the present surface characteristics will be modified to remove potential flooding hazards. Adequate water supplies for construction, operation, and closure are available from aquifers within the geohydrologic setting; wells can be located away from competitive users. Available technology can be used to control water inflows from aquifers over the dome.	
	Tectonics 960.5-2-11	Active tectonic processes would not lead to disruption of the repository function,	

Table 6-15. Preclosure System Guideline Requiring Site Characterization, Richton Dome Site (Page 3 of 3)

System Guideline 960.5-1(a)(3) Ease and Cost of Construction, Operation, and Closure	Associated Technical Guidelines	Assessment Results	Finding
	Tectonics 960.5-2-11 (continued)	based on the absence of Quaternary fault displacements and volcanism, and the low level of historical seismicity (infrequent and of low magnitude). No tectonic processes are anticipated that would lead to unallowable preclosure releases of radionuclides.	

that the site is not likely to meet the qualifying conditions. Therefore it is concluded that the Richton Dome site is suitable for site characterization.

6.4 PERFORMANCE ASSESSMENTS

This section presents preclosure and postclosure modeling assessments in support of conclusions about whether the site complies with the quantitative requirements of the 10 CFR Part 60 guidelines evaluated in Sections 6.2 and 6.3.

6.4.1 Preclosure Radiological Assessment for Richton Dome

This section summarizes the evaluations of the preclosure offsite radiological conditions outside the restricted area that are required for the Richton Dome site. Details of all data, methods, and results are given in Waite et al. (1985, BMI/ONWI-541, Revision 1). Because of the conservative assumptions made in the analyses, actual repository performance is likely to prove better than documented in this section.

6.4.1.1 Guideline Requirements

The radiological protection requirements pertinent to this discussion are found in 10 CFR Part 60 which defers to 10 CFR Part 20, and 40 CFR Part 191. 10 CFR Part 20 covers both occupational and offsite radiological safety requirements. Occupational radiation exposure to repository workers has been considered. 10 CFR Part 20 establishes standards which limit the exposure of workers to radiation. The nuclear industry has had a great deal of experience in maintaining worker doses below these NRC limits. Both engineering controls and radiation protection practices are commonplace in the industry. Also, specific studies on repository worker exposures have been done. These include Kaiser Engineers, 1978; Stearns-Rogers, 1979, ONWI-283; DOE, 1980, DOE/EIS-0046F, Vol. 1; and Bechtel Group, 1981, ONWI-258, Vols. I-V. All of these studies report that repository worker exposures can be kept below regulatory requirements. Although there is a large data base in this area, a more detailed repository design is needed before a rigorous quantitative evaluation of occupational exposures can be performed. This evaluation will be presented in the Environmental Impact Statement for the repository. There are two offsite requirements that are applicable. The standards that must be satisfied if the NRC is to grant a license include the following:

1. The applicant must demonstrate that the proposed operations are not likely to cause any individual in an unrestricted area (maximum exposed individual) to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem (10 CFR 20.105[a]).

2. The licensee must not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations that exceed the limits specified in Appendix "B," Table II (Maximum Permissible Concentration Table for Unrestricted Areas, 10 CFR 20.103[a][1]).

Section 40 CFR 191.03(a) requires that the combined annual dose equivalent to any member (maximum exposed individual) of the public due to operations covered by 40 CFR Part 190 and to direct radiation and planned discharges of radioactive materials covered by this subpart shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ. 40 CFR 191.03(b) and 40 CFR 191.04 allow for less stringent requirements in some cases. However, the 40 CFR 191.03(a) requirements are more restrictive than these and the 10 CRF Part 20 requirements are used in these analyses.

The comparisons required by the guidelines include the 10 CFR Part 20 concentration limits, which will be discussed first, and the 40 CFR Part 191 (maximum exposed individual) dose limits. To lend further insight into the radiological impacts of the presence of a high-level nuclear waste repository at a specific location, the population doses associated with the 40 CFR Part 191 analyses and accident doses have also been included at the end of this discussion. The 10 CFR Part 20 concentration analysis is presented first.

The phases of the repository that are specifically addressed here are construction and operation. The closure phase, the analysis of which is also required by the guidelines, is not addressed explicitly because documentation of all previous decommissioning studies indicates that the radioactive emissions during decommissioning can be controlled to levels far below those during the operational period (BNW, 1979, DOE/ET-0028). For instance, it has been estimated (Smith et al., 1978, NUREG/CR-0130) that during the complete dismantling of a 1,175 megawatts of electricity MW(e) pressurized water reactor (PWR) only 85 microcuries of radioactive materials would be released to the environment. Even though there is a marked difference between a reactor and a repository, the reactor analogy appears to be appropriate to provide a reasonable estimate of the upper bound for potential repository impacts since release values are expected to be much smaller in the case of the repository. This is partially because there will be less residual mobile contamination at a repository than at a power reactor.

6.4.1.2 10 CFR Part 20 Calculation

To show compliance with 10 CFR Part 20, the sum of the individual maximum radionuclide concentrations to maximum permissible concentrations (MPC) ratios in the unrestricted area must be compared to unity. A result less than one demonstrates compliance. The information required for this calculation includes (1) the release rate of each radionuclide; (2) the atmospheric dispersion characteristics of the site under worst-case meteorological conditions; and (3) the point of maximum radionuclide concentration in the unrestricted area.

The radionuclides anticipated to be released during construction and operation are shown in Tables 6-16 and 6-17, respectively. During the excavation of salt from the repository vault, it is expected that the release of naturally occurring radionuclides contained in the salt will be enhanced. The main radionuclides of interest here are radon (Rn-222) and thoron (Rn-220) and their progeny.

During the routine operation of the repository, releases originating from the disassembly of the spent fuel elements are expected. Additional information about the assumptions and basis for these analyses can be found in Waite et al. (1985, BMI/ONWI-541). The disassembly process consists of removing the end fittings and spacers from the assembly so that the individual rods may be placed in canisters in a geometrically efficient manner. Based on a study by the Nuclear Assurance Corporation (1981, DOE/ET-47912-1), a damage rate for fuel cladding during the disassembly operation has been established. The four radionuclides listed in Table 6-17, H-3, C-14, Kr-85, and I-29, represent the volatile fission gases that will be released in the event of cladding damage. The actual release values were calculated as follows:

1. A damage fraction of 0.005 was established, based on the conservative assumption that 1.0 percent of the rods stick within the assembly. It is also assumed that 50 percent of the stuck rods are damaged as they are forced out of the assembly.

2. The number of damaged rods that can be expected in 1 year is calculated by multiplying the number of rods received per year by the damage fraction. The maximum annual release is calculated based on the maximum number of rods expected in 1 year. The average annual release is based on an average annual rod receipt rate.

3. The amounts released are determined by multiplying the number of damaged rods, either maximum or average, by the emission from the damage of one rod.

The values listed in Table 6-17 are based only on the receipt of spent fuel as a waste form. While other designs call for the receipt of vitrified waste, the assumption of 100 percent spent fuel as the waste form bounds the release. This is the case since there are no routine operational releases associated with vitrified wastes because of the absence of the volatile radionuclides.

It can be assumed that the emission rate of construction-related radionuclides will continue relatively unchanged during the operational period because mining will also continue during the operational period. Therefore, if only spent fuel is being handled, the total

Table 6-16. Radionuclide Emissions During Construction

Radionuclide	Annual Release Curies (Ci)	Release Rate Ci/sec
Rn-222	2.9×10^{-4}	9.2×10^{-12}
Po-218	2.9×10^{-4}	9.2×10^{-12}
Pb-214	2.9×10^{-4}	9.2×10^{-12}
Bi-214	2.9×10^{-4}	9.2×10^{-12}
Po-214	2.9×10^{-4}	9.2×10^{-12}
Pb-210	2.9×10^{-4}	9.2×10^{-12}
Bi-210	2.9×10^{-4}	9.2×10^{-12}
Po-210	2.9×10^{-4}	9.2×10^{-12}
Rn-220	2.2×10^{-4}	7.0×10^{-12}
Po-216	2.2×10^{-4}	7.0×10^{-12}
Pb-212	2.2×10^{-4}	7.0×10^{-12}
Bi-212	2.2×10^{-4}	7.0×10^{-12}
Po-212	1.4×10^{-4}	4.4×10^{-12}
Tl-208	7.8×10^{-5}	2.5×10^{-12}

Source: Waite et al., 1985, BMI/ONWI-541, Revision 1.

Table 6-17. Radionuclide Emissions During Operation

Radionuclide	Annual Average Release, Curies	Maximum Annual Release, Curies
H-3	$3.2 \times 10^{+1}$	$5.6 \times 10^{+1}$
C-14	2.6×10^{-1}	4.4×10^{-1}
Kr-85	$1.9 \times 10^{+4}$	$3.4 \times 10^{+4}$
I-129	3.2×10^{-2}	5.6×10^{-2}

Source: Waite et al., 1985, BMI/ONWI-541, Revision 1.

operational release is the sum of the "construction" and "operation" source terms. If only high-level waste is being handled, then the total "operational" release is that represented by the "construction" source terms.

Dispersion values are applied to the radionuclide emission rates to factor in atmospheric dilution, resulting in concentrations of the released material. The maximum concentrations will occur at the point of the maximum X/Q value. For the purposes of this calculation, worst-case meteorology was assumed since these values will yield the greatest concentrations. These assumptions include a Pasquill stability class of F and a wind speed of 1.0 meters per second.

Results are given in Table 6-18. The maximum concentrations occur at 5,000 meters (16,404 feet) from the site. This point is where the maximum sum of concentrations to MPC ratios occurs. The sum at this point is 0.05. Thus, the repository facility combined releases during the operational phase are only 5 percent of the NRC limit. This analysis was done only for the operational phase, since the releases during that time would be always greater than during the construction phase. Table 6-18 also shows that krypton-85 is the only radionuclide that contributes significantly to the sum. The radionuclides polonium-218, polonium-214, polonium-216, and polonium-212 were excluded from the calculation because of their short half-lives. They will decay before they reach the unrestricted area.

6.4.1.3 40 CFR Part 191 Calculation

This calculation must be done for all potential exposure pathways (submersion, inhalation, and ingestion) at the geographical location that potentially yields the maximum dose available to an individual. An individual at the point of maximum radionuclide concentration is assumed to be the maximum exposed individual in these calculations.

The radionuclide release rates are the same for this calculation as those shown in Tables 6-16 and 6-17. However, in contrast to the 10 CFR Part 20 calculation, annual average meteorological characteristics were used to calculate the radionuclide concentrations used in dose assessments.

The National Oceanic and Atmospheric Administration (NOAA) has developed the following atmospheric classification system (NOAA, 1975):

Classification A = extremely unstable conditions
Classification B = moderately unstable conditions
Classification C = slightly unstable conditions
Classification D = neutral conditions
Classification E = slightly stable conditions
Classification F = moderately stable conditions.

As the classification increases from A to F, the atmospheric dispersion of the radionuclides decreases.

The meteorological data presented in the "Distribution of Pasquill Stability Classes Report" (NOAA, 1975) indicate a typical Stability Classification F and an average wind speed of 3.3 meters per second (10.8 feet per second) for the Richton Dome area. These data were used to calculate the radionuclide concentrations and the appropriate dose calculations were made using these concentrations. Site-specific agricultural data (Mississippi Department of Agriculture and Commerce and U.S. Department of Agriculture Statistical Reporting Service, 1983) were used for ingestion calculations; site independent dose factors were used in the submersion (Kocher, 1983) and inhalation (ICRP, 1982) calculations. Following examination of the doses to individual organs to ensure compliance with applicable regulations, methods recommended in ICRP-26 (ICRP, 1977) were used to combine doses to different organs into the results shown in Table 6-19. Details of this process are to be found in Section 3.2 of Waite et al., 1985, BMI/ONWI-541.

Table 6-18. 10 CFR Part 20 MPC[a] Comparison

Radionuclide	Emission Rate ■Ci[b]/sec	Concentration ■Ci/cm^3	MPC ■Ci/cm^3	Conc/MPC
Rn-222	9.2×10^{-6}	1.8×10^{-15}	3.0×10^{-9}	6.0×10^{-7}
Pb-214	9.2×10^{-6}	1.8×10^{-15}	3.0×10^{-6}	6.0×10^{-10}
Bi-214	9.2×10^{-6}	1.8×10^{-15}	3.0×10^{-6}	6.0×10^{-10}
Pb-210	9.2×10^{-6}	1.8×10^{-15}	4.0×10^{-12}	5.0×10^{-4}
Bi-210	9.2×10^{-6}	1.8×10^{-15}	2.0×10^{-10}	9.0×10^{-6}
Po-210	9.2×10^{-6}	1.8×10^{-15}	2.0×10^{-11}	9.0×10^{-5}
Rn-220	7.0×10^{-6}	1.4×10^{-15}	1.0×10^{-8}	1.0×10^{-7}
Pb-212	7.0×10^{-6}	1.4×10^{-15}	6.0×10^{-10}	2.0×10^{-6}
Bi-212	7.0×10^{-6}	1.4×10^{-15}	3.0×10^{-9}	5.0×10^{-7}
Tl-208	2.5×10^{-6}	5.5×10^{-15}	3.0×10^{-6}	2.0×10^{-9}
H-3	1.7	2.2×10^{-11}	2.0×10^{-7}	1.0×10^{-4}
C-14	1.4×10^{-2}	1.9×10^{-13}	1.0×10^{-6}	2.0×10^{-7}
Kr-85	$1.0 \times 10^{+3}$	1.3×10^{-8}	3.0×10^{-7}	5.0×10^{-2}
I-129	1.7×10^{-3}	2.2×10^{-14}	2.0×10^{-11}	1.0×10^{-3}
			TOTAL =	5.0×10^{-2}

(a) MPC= Maximum Permissible Concentration.
(b) ■Ci = microcurie.

Table 6-19. Richton Region Dose Comparison

Construction	
Maximum Exposed Individual	
Annual Dose[a]	4.1×10^{-1} mrem
50-year Dose Commitment	3.7 mrem
Population	
50-year Dose Commitment	1.1×10^{5} man-mrem
Operation	
Maximum Individual	
Annual Dose[a]	6.6×10^{-1} mrem
50-year Dose Commitment	2.2×10^{1} mrem
Population	
50-year Dose Commitment	1.9×10^{6} man-mrem

(a) This value represents the annual dose from a one-year exposure to the release. This result is the one that should be compared with the 25 mrem whole body dose limit.

Although not called for in the guidelines, the population doses out to 80 kilometers (50 miles) for the construction and operational phases of the repository are also shown in Table 6-19 because they provide insight into site differences. For these calculations site-specific demographic data detailed in BMI-ONWI-541 Revision 1 (Waite et al., 1985) were used. The population dose results are shown in units of man-mrem. There are no regulatory limits to which these can be compared. The doses, however, are orders of magnitude below natural background levels.

6.4.1.4 Accident Calculations

Studies of waste handling operations in a repository were performed in conjunction with the preparation of the Final Environmental Impact Statement (FEIS) (DOE, 1980, DOE/EIS-0046F; Yook et al., 1984, BMI/ONWI-551) to identify potential accidents in the handling of the waste and to estimate radionuclides that might be released. Based on these studies, with their inherent level of detail based on very early designs, it was envisioned that these accidents bound the set of potential scenarios and source terms. Also, every effort has been made to pursue a conservative approach to the analysis of impacts of these selected accidents. Any contention that the analyses are complete must await forthcoming improvements in definitions of repository designs and activities. Since the facility design (Section 5.1) being used for impact assessments for this EA embodies the same basic fuel handling operations, the same accidental events developed for the FEIS were used.

Accidents analyzed consist of the following:

1. Shaft Hoist Failure, Spent Fuel (SF)

   For this accident, shaft hoist failure is assumed while a waste package containing spent fuel is being lowered into the mine for emplacement. Rupture upon impact is postulated with a fractional release of the radioactive content into the ventilation exhaust air stream. Exhaust to the outside occurs via filters and out the stack. The release is assumed to occur over a 1-hour period. This release is from ground level.

2. Shaft Hoist Failure, Commercial High-Level Waste (CHLW)

   This is the same accident event as (1), but the waste package is assumed to hold commercial high-level waste (CHLW). This release is from ground level.

3. Handling Accident, Receiving Area (SF)

   In this scenario, a handling mishap is postulated in the receiving area. A cask used for transporting spent fuel to the repository and containing 12 pressurized water reactor (PWR) spent fuel assemblies is crushed by another cask dropped during handling. Release of a fraction of the radioactive inventory in the fuel (gases and particulates) into the receiving area is assumed. This release is from an elevated release point.

4. Hoist Failure, Remote-Handled Transuranic Waste (Remote TRU)

   This is the same accident event as (1) and (2) except that four canisters carrying three drums each of remote-handled transuranic wastes are dropped down the mine shaft and burst. It assumes 20 percent of the material is released from the drums. This release is from ground level.

5. Handling Accident, Operations Area, Contact-Handled Transuranic Waste (Contact TRU)

   In this scenario, a handling accident causes puncture of a drum containing contact-handled transuranic wastes. Fractional release of the contents into the operations area is assumed. This release is from an elevated release point.

These accident scenarios are believed to provide bounding conditions, i.e., result in an upper limit to the consequences that might be experienced from waste handling accidents.

The meteorological conditions assumed were F stability class and 1 meter per second (2.2 feet per second) wind speed (NRC, 1972). This is a conservative approach since it portrays very poor dispersion conditions, thus producing a worst case analysis. The method for the dose assessment is the same as for the routine releases except for one significant change: the exposure from the ingestion of contaminated food is ignored. It is assumed that all foodstuffs grown in the area affected by the accidental release will be collected and surveyed for signs of contamination. Therefore, this pathway will be cut off. The radionuclide source terms are as shown in Tables 6-20 through 6-24 (Waite et al., 1985, BMI/ONWI-541, Revision 1). The maximum exposed individual is assumed to be at the point of maximum radionuclide concentration in the unrestricted area. For population doses, the assumption is made that the release is into the most populous sector surrounding the release point. The 50-year dose commitment results are shown in Table 6-25. There are no regulatory limits to which these results can be compared.

6.4.2 Preliminary Postclosure Performance Assessment

In this section, a preliminary postclosure performance assessment is made for each of the three major subsystems of the Richton Dome waste-disposal system: the waste package, the engineered-barrier subsystem, and the geologic subsystem.

6.4.2.1 Scope and Objective

The evaluation of the proposed Richton Dome site with respect to 10 CFR Part 960, Subparts C and D, provides part of the basis for site nomination. The guidelines specify that the evaluation be made using preliminary performance assessments to estimate the likelihood of satisfying regulatory performance criteria contained in the NRC 10 CFR Part 60 regulation and the EPA 40 CFR Part 191 regulation. A preliminary performance assessment of the Richton Dome site is presented in this section, and results of the assessment are used in Section 6.3.2, postclosure System Guideline, as part of the evaluation of the site.

Because of current limitations on the data base and analytical methods, this preliminary assessment is not intended to demonstrate satisfaction of the postclosure System Guideline; rather, it is intended to supplement the evidence that will be used to establish whether the Richton Dome site is suitable for site characterization. A performance assessment that will be used to demonstrate satisfaction of the postclosure System Guideline is contingent upon and will follow site characterization.

Section 6.4.2 is organized into several subsections. Section 6.4.2.2 contains descriptions of the three major subsystems of the proposed Richton Dome waste-disposal system: the waste package, the engineered barrier subsystem, and the geologic subsystem. The individual performance of each of these major subsystems is evaluated in Section 6.4.2.3. The specific objectives of these evaluations are (1) to satisfy the need for preliminary performance assessment of subsystems as specified in Subpart B of 10 CFR Part 960; and (2) to establish the Reference Case system configuration to be used in the analysis of Section 6.4.2.4. Section 6.4.2.4 contains a preliminary assessment of total system performance. In Section 6.4.2.5, subsystem and total system performance discussed in earlier sections are evaluated in terms of the applicable performance objectives of 10 CFR Part 60 and 40 CFR Part 191. The objective of these evaluations is to establish a rough measure of undisturbed system performance. A brief discussion of system performance under disturbed conditions, such as human intrusion and disruptive events, is provided in Section 6.4.2.6. Conclusions are summarized briefly in Section 6.4.2.7.

Code Status. The status of various individual codes planned for performance assessments for licensing is described in the Performance Assessment Plan (ONWI, 1984, BMI/ONWI-545). Codes used for preliminary performance assessments for the statutory environmental assessment described here are (1) a radionuclide inventory source term code, ORIGEN2, (2) a time-dependent thermal analysis code, TEMPV5, (3) a brine migration code, BRINEMIG, (4) a nuclear

Table 6-20. Radioactive Releases From Shaft Drop of CHLW[a,b]

Radionuclide	Released Curies
Y-90	3.9×10^{-4}
Sr-90	3.9×10^{-4}
Ru-106	4.4×10^{-5}
Te-125	4.8×10^{-6}
Cs-134	8.0×10^{-5}
Cs-137	6.0×10^{-4}
Ce-144	2.0×10^{-5}
Eu-154	3.6×10^{-5}
Pu-238	5.6×10^{-7}
Pu-239	1.3×10^{-8}
Pu-240	5.2×10^{-8}
Pu-241	6.4×10^{-6}
Am-241	5.2×10^{-6}
Cm-244	4.4×10^{-5}

(a) CHLW = Commercial High-Level Waste.
(b) The release is assumed to occur over a 1-hour time period.

Table 6-21. Radioactive Releases From Shaft Drop of Spent Fuel[a]

Radionuclide	Released Curies
H-3	9.0
C-14	6.0×10^{-2}
Kr-85	$6.0 \times 10^{+3}$
Sr-90	2.0×10^{-4}
Y-90	2.0×10^{-4}
I-129	9.0×10^{-3}
Cs-137	2.3×10^{-4}
Pu-238	6.0×10^{-6}
Pu-239	8.7×10^{-7}
Pu-240	1.4×10^{-6}
Pu-241	2.1×10^{-4}
Am-241	4.8×10^{-6}
Cm-244	2.7×10^{-6}

(a) The release is assumed to occur over a 1-hour time period.

Table 6-22. Radioactive Releases From Shaft Drop of Remote-Handled TRU[a]

Radionuclide	Released Curies
H-3	2.5×10^{-1}
C-14	4.4×10^{-4}
Mn-54	8.1×10^{-8}
Co-60	1.6×10^{-6}
Ni-63	1.6×10^{-7}
Sr-90	1.2×10^{-8}
Nb-95	8.2×10^{-8}
Cs-137	1.9×10^{-8}
Pu-238	1.1×10^{-9}
Pu-239	7.2×10^{-11}
Pu-240	1.5×10^{-10}
Pu-241	3.6×10^{-8}
Am-241	1.4×10^{-10}
Cm-242	2.0×10^{-9}
Cm-244	1.4×10^{-9}

(a) The only credible accidents that happen with the remote-handled TRU (some 34,365 drums) are bounded in consequences by the shaft drop. In this accident, four canisters carrying three drums each are assumed to be dropped down the mine shaft and burst. Some 20 percent of the material is assumed to be released from the drums.

Table 6-23. Radioactive Releases From Spent Fuel Handling Accident[a]

Radionuclide	Released Curies
H-3	5.4
C-14	3.6×10^{-2}
Kr-85	$3.6 \times 10^{+3}$
I-129	5.4×10^{-3}

(a) In this accident, the 12 PWR assemblies in a railcar cask are somewhat crushed in the receiving building, by a second cask. Because of filtration, virtually all of the particulate is contained. However, the gases are not totally filtered. It is assumed that 30 percent of the void gases in the pins would be released by the accident.

Table 6-24. Radioactive Releases From Contact-Handled TRU Puncture Accident[a]

Radionuclide	Released Curies
H-3	6.3×10^{-6}
C-14	1.6×10^{-10}
Co-60	6.2×10^{-13}
Sr-90	9.2×10^{-13}
Nb-95	1.1×10^{-11}
Ru-106	2.8×10^{-10}
I-129	1.6×10^{-4}
Cs-134	1.8×10^{-12}
Cs-137	1.4×10^{-12}
Pu-238	8.2×10^{-12}
Pu-239	5.4×10^{-13}
Pu-240	1.1×10^{-12}
Pu-241	2.7×10^{-10}

(a) The most credible accident that can happen to contact-handled TRU is the puncture of the drum and subsequent release of the drum's contents.

Table 6-25. Richton Region Accident Dose Commitment Comparison

I.	SF Hoist Accident	50-year Dose Commitment
	Maximum Individual	$4.68 \times 10^{+1}$ mrem
	Population	$2.86 \times 10^{+3}$ man-mrem
II.	CHLW Hoist Drop	
	Maximum Individual	2.74 mrem
	Population	$1.67 \times 10^{+2}$ man-mrem
III.	SF Handling	
	Maximum Individual	3.98×10^{-2} mrem
	Population	$1.14 \times 10^{+3}$ man-mrem
IV.	Remote-TRU Hoist Drop	
	Maximum Individual	3.10×10^{-3} mrem
	Population	1.89×10^{-1} man-mrem
V.	Contact-TRU Handling	
	Maximum Individual	2.07×10^{-9} mrem
	Population	5.95×10^{-5} man-mrem

radiation shielding analysis code, ANISN-W, and (5) a waste package performance code, WAPPA. The status of documentation, verification, and validation activities is variable for these codes and their use here does not suggest their use in future performance assessments. The status of all except TEMPV5 is given in the Performance Assessment Plan (PAP). TEMPV5 is a modified version of TEMP, which is described in the PAP. The major change in the TEMPV5 modification was to include in the analytical model the important fact that the thermal conductivity of salt decreases with increasing temperatures. Additional details about each code are given in the appropriate following sections.

6.4.2.2 Subsystem Descriptions

For the purpose of these assessments, it is assumed that a repository at Richton Dome would be located entirely within the salt contained in the Richton Dome. The top of the dome, at depths of about 152 to 305 meters (500 to 1,000 feet) below ground surface, is overlain by a freshwater aquifer system of unconsolidated sand, gravel, silt, and clay layers. The underground working areas of approximately 809 hectares (2,000 acres) would be located about 655 meters (2,150 feet) from the surface (Table 5-1). Mined areas would occupy no more than 30 percent of the underground working areas. For this preliminary performance assessment, it is assumed that the waste inventory will be 10-year-old spent fuel (SF) and/or commercial high level waste (CHLW) after a burnup of 32,717 megawatt days per metric ton with intermittent shutdowns representing 72,000 metric tons (79,365 tons) of heavy metal (Ludwig, 1984). The first repository, as specified in the Nuclear Waste Policy Act (NWPA) of 1982 (42 USC Sections 10101-10226), can contain up to 70,000 metric tons (77,161 tons) until a second repository becomes available. The 72,000 metric tons (79,365 tons) used in this repository concept is conservatively high with respect to the NWPA interim limit for the first repository. The repository concept described in Chapter 5 included approximately 36,000 metric tons (39,682 tons) of heavy metal of SF and CHLW and quantities of transuranic (TRU) and defense high-level wastes (DHLW). TRU and DHLW wastes do not generate significant quantities of heat and will be emplaced in zones that do not have significant increases in temperature caused by dissipation of the heat from high-level wastes. Thus, preliminary performance assessments of CHLW and SF may be performed independent of the presence of these other wastes. Performance assessments accompanying site characterization will include DHLW and TRU. Performance assessments are performed for the two cases that bracket the expected performance of the repository concept, that is, Case I - 100 percent SF; Case II - 100 percent CHLW. Radionuclide inventory compositions obtained from ORIGEN2 (Jansen, 1985) computer runs for spent fuel from pressurized water reactors (SFPWR) and CHLW are listed in Table 6-26.

Functionally, the waste-disposal system is made up of three major subsystems: (1) the waste package; (2) the mined repository including additional engineered barriers, if any; and (3) the geologic, including geohydrologic and geochemical, setting of the site. Those parts of each of the three subsystems relevant to postclosure systems performance are described below.

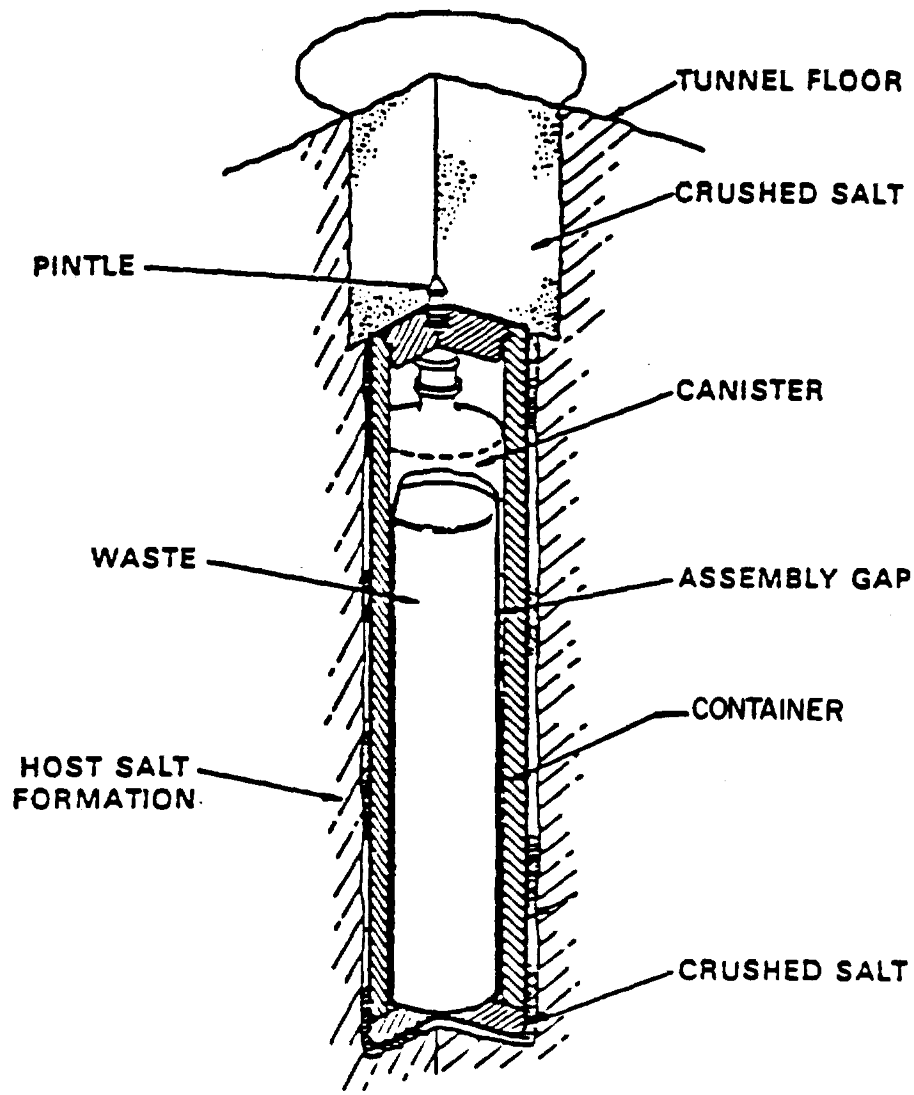
6.4.2.2.1 Waste Package Subsystem. The waste package configuration that was analyzed is the borehole emplacement concept shown in Figure 6-2, which was designated Alternate II by Westinghouse Electric Corporation (1983, ONWI-438, pp. 14, 16). Since the waste package design is continuing, the final design is not available but results should be typical of what can be achieved. The 52-centimeter (20.5-inch)-diameter, 3.7-meter (12.1-foot)-long spent fuel waste form is made up of close-packed, disassembled pressurized water reactor (PWR) fuel pins from 10 PWR assemblies (4.614 metric tons [5.086 tons] of heavy metal in a thin-walled canister). There will also be spent fuel from boiling water reactors (SFBWR), which will be emplaced in a repository. Radionuclide inventory differences per unit weight of SF are insignificant for the purposes of this report. This analysis will consider only the SFPWR which, when loaded in the Alternate II package design, generate more heat per package than SFBWR. Thus, the analysis is conservative. The commercial high-level waste form (CHLW) is 76-68 borosilicate glass (Westsik et al., 1983, PNL-3172, p. 5) containing reprocessed waste from 9.65 metric tons (10.63 tons) of heavy metal of nuclear fuel. The SFPWR canister is surrounded by a 12-centimeter (4.7-inch)-thick container wall of low-carbon steel. The CHLW package has a 15-centimeter (5.9-inch)-thick container wall of the same material. The borehole is backfilled with about 2 centimeters (0.8 inch) of crushed salt around the package

Table 6-26. Radionuclide Inventories in 72,000 Metric Tons of Heavy Metal of SFPWR and the Equivalent of 72,000 Metric Tons of Heavy Metal of CHLW at Various Times After Emplacement

Nuclide	Half-Life, yr	Inventory, Ci 0 yr		200 yr		1,000 yr	
		CHLW	SFPWR	CHLW	SFPWR	CHLW	SFPWR
C-14	5,730	111,000[c]	111,000	108,000[c]	108,000	98,000[c]	98,000
Se-79	65,000	29,200	29,200	29,100	29,100	28,900	28,900
Sr-90	28.9	4.09E + 9[b]	4.09E + 9	3.50E + 7	3.50E + 7	0.188	0.188
Tc-99	213,000	933,000	934,000	932,000	933,000	930,000	931,000
Sn-126	100,000	55,300	55,300	55,200	55,300	54,900	55,000
I-129	1.60E + 7	2,250[c]	2,250	2,250[c]	2,250	2,250[c]	2,250
Cs-135	2.30E + 6	24,200	24,200	24,200	24,200	24,200	24,200
Cs-137	30.2	5.87E + 9	5.87E + 9	5.77E + 7	5.78E + 7	0.542	0.542
Th-232	1.40E + 10	1.07E - 5	1.07E - 5	1.16E - 5	1.93E - 4	1.53E - 5	9.43E - 4
U-233	159,000	0.00976	1.96	22.7	28.5	152	232
U-235	7.04E + 8	6.29	1,260	6.31	1,260	6.42	1,280
U-236	2.34E + 7	91.9	18,400	94.3	18,600	104	19,500
U-238	4.47E + 9	114	22,900	114	22,900	114	22,900
Np-237	2.14E + 6	22,400	22,400	29,100	38,400	42,000	71,400
Pu-238	87.7	8.16E + 5	1.63E + 8	354,000	3.38E + 7	9,860	70,500
Pu-239	24,100	113,000	2.25E + 7	120,000	2.24E + 7	143,000	2.19E + 7
Pu-240	6,540	188,000	3.77E + 7	431,000	3.72E + 7	396,000	3.41E + 7
Pu-241	14.7	2.77E + 7	5.54E + 9	11,700	375,000	9,240	9,240
Pu-242	376,000	609	122,000	629	122,000	643	122,000
Am-241	432	1.21E + 8	1.21E + 8	8.83E + 7	2.26E + 8	2.45E + 7	6.27E + 7
Am-243	7,380	1.19E + 6	1.19E + 6	1.17E + 6	1.17E + 6	1.08E + 6	1.08E + 6
Cm-244	18.1	9.07E + 7	9.08E + 7	43,000	43,000	2.16E - 9	2.17E - 9
Cm-245	8,500	10,000	10,000	9,850	9,850	9,220	9,230

Note: Apparent discrepancies may appear because of rounding to 3 significant figures.

(a) ORIGEN2 computer runs made for SRPO data base - 32,717 MWD/tonne burnup with intermittent shutdowns (Jansen, 1985).
(b) 4.09E + 9 = 4,090,000,000.
(c) This element is not in the CHLW inventory. It would be separated in the fuel reprocessing plant.



Configuration of Emplaced Waste Package

Source: Jansen, 1985

Figure 6-2

and backfilled up to the floor level with crushed salt. The waste is assumed to be emplaced 10 years after the fuel is discharged from the reactor, with the CHLW package initially generating 9.5 kilowatts of heat and the SFPWR package generating 5.5 kilowatts (Jansen, 1985). The waste package dimensions are given in Table 6-27. As corrosion proceeds, oxide corrosion products accumulate in the space previously occupied by the steel overpack. This process is described in more detail in Section 6.4.2.3. The canister is expected to last only a few years after failure of the container. This analysis ignores whatever containment would be provided by the canister.

6.4.2.2.2 Engineered Barrier Subsystem. The guidelines state that the "Engineered-barrier system is the man-made components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting, which includes radioactive waste from radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility." At this time, no engineered barriers other than the waste package are included for repositories in salt. Any containment or sorption effects provided by the crushed salt backfill in repository rooms (and around the waste packages) are ignored for the purpose of this performance assessment. General descriptive information about the repository concept is given in the following paragraphs. Refer to Chapter 5 for more details.

Waste packages are to be emplaced in single rows in the floor of each storage room as shown in Figure 6-3. Repository areal loadings at the time of emplacement of 15 and 30 watts per square meter for SF and CHLW, respectively, were chosen. These areal loadings do not include areas associated with shafts, TRU rooms, etc. The area associated with each package is the area defined by the intersections of lines drawn midway between packages parallel to and perpendicular to the storage tunnels, which is equal in area to S x P_L (see Table 6-28 and Figure 6-3). Tunnels are to be backfilled with crushed salt.

For the purpose of this preliminary performance assessment, the engineered barrier subsystem boundary is the outside surface of each overpack of each waste package. Hypothetical nuclide releases from the engineered barrier subsystem to the geologic subsystem are assumed to commence at the time of overpack failure and are assumed to be limited only by the quantity of each nuclide that would dissolve into the quantity of brine available (ignoring the consumption of brine by chemical reaction with the overpack). Further details are given in Section 6.4.2.3.

6.4.2.2.3 Geologic Subsystem. The geologic subsystem includes an alternative sequence of aquifers and confining units that were pierced by the Richton Dome (see Section 3.2.3, Figure 3-11 for a geologic cross section of the dome). The dome is overlain by a fresh-water unconsolidated aquifer system that extends from the ground surface to depths of about 152 to 305 meters (500 to 1,000 feet). The two main aquifers surrounding the dome are the Upper Claiborne unit (at depths of 396 to 549 meters [1,300 to 1,800 feet]) and the Wilcox Group (at depths from about 762 to 1,524 meters [2,500 to 5,000 feet]). The aquifers described above are separated by confining units (aquitards) several hundred feet thick.

Ground water in the Upper Aquifer generally contains less than 1,000 parts per million total dissolved solids (TDS) and the heads vary from about 3 to 91 meters (10 to 300 feet) above mean sea level (MSL). The head in the Upper Claiborne Unit is about 31 to 76 meters (100 to 250 feet) above MSL and the ground-water TDS content varies from 3,000 to 40,000 parts per million. Ground water in the Wilcox Unit is also under artesian pressure, with heads from about 46 to 82 meters (150 to 270 feet) above MSL and TDS content of 10,000 to 50,000 parts per million.

It is proposed that the repository be constructed in the salt dome at a depth of 648 meters (2,125 feet) below ground surface, which will leave a thickness of more than 305 meters (1,000 feet) of domed salt above the top of the repository. The horizontal extent of the repository will be kept at a minimum distance of 244 meters (800 feet) from the side of the dome. See Chapters 3 and 5 for more details.

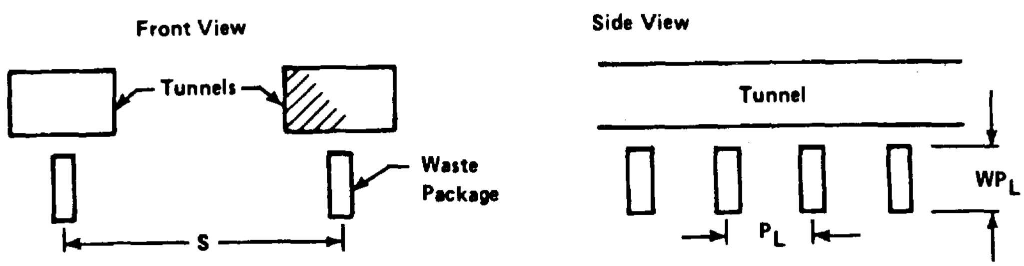
Table 6-27. Uncorroded Waste Package Cross-Section Dimensions

Material	Inner Radius, cm	Wall Thickness, cm	Outer Radius, cm	Diameter Inner, cm	Diameter Outer, cm
			CHLW Borehole Concept Reference Package (ONWI-438, Table 1.2, p. 14, Designated Alternate II)		
Waste	0.00	26.73	26.73	0.00	53.46
Canister[a]	26.73	1.27	28.00	53.46	56.00
Oxide	28.00	0.00	28.00	56.00	56.00
Air Gap	28.00	1.50	29.50	56.00	59.00
Container[b]	29.50	15.00	44.50	59.00	89.00
Oxide	44.50	0.00	44.50	89.00	89.00
Crushed Salt	44.50	2.50	47.00	89.00	94.00
			SFPWR Borehole Concept Reference Package (ONWI-438, Table 1.3, p. 16, Designated Alternate II)		
Waste	0.00	27.86	27.86	0.00	55.73
Canister[a]	27.86	0.64	28.50	55.73	57.00
Oxide	28.50	0.00	28.50	57.00	57.00
Air Gap	28.50	1.25	29.75	57.00	59.50
Container[b]	29.75	12.00	41.75	59.50	83.50
Oxide	41.75	0.00	41.75	83.50	83.50
Crushed Salt	41.75	2.75	44.50	83.50	89.00

Note: The salt dimension is good only to the nearest horizontal neighbors.

(a) 316 stainless steel.
(b) Low-carbon steel.

Source: Westinghouse Electric Corporation, 1983, ONWI-438.



Repository High-Level Waste Storage Placement

Figure 6-3

Table 6-28. Repository High-Level Waste Storage Parameters

Waste[a] Form	Area Loading[b], W/M^2[c]	Waste Packages[b] per Room	Number[b] of Waste Packages	Overpack[a] Outer Diameter[d]	P_L[b][d]	S[b][d]	WP_L[a][d]
SFPWR	15	9	7,899	0.835	18.3	20.1	3.85
CHLW	30	13	3,673	0.890	12.2	26.2	3.68

(a) Westinghouse Electric Corporation, 1983, ONWI-438.
(b) SCC, 1984b.
(c) W/M^2 = watts per square meter.
(d) Dimensions in meters (m).

The expected performance of the geologic subsystem for a salt repository is approximated by considerations of (1) the migration of brine toward the heat sources provided by the waste packages, (2) the possible mobility of brine, with dissolved radionuclides, by diffusion away from waste packages after package failure, and (3) the flow of ground water, with dissolved radionuclides, toward the accessible environment if radioactivity has been encountered by the ground water for any reason. Sorption of radionuclides by salt is considered to be low and is ignored for this performance assessment. Sorption to varying degrees would occur in the ground-water system and will be considered in those cases, if any, where radioactivity has been encountered by ground water. The extent of the disturbed zone will be estimated and its impact upon water travel times estimated. The contamination of major sources of ground water by radioactivity will be estimated as required by 40 CFR Part 191. Additional details concerning the processes and phenomena that impact radionuclide transport are given in Section 6.4.2.3. Additional details concerning the characteristics of the geologic subsystem are given in Chapter 3.

6.4.2.3 Preliminary Subsystem Performance Assessments

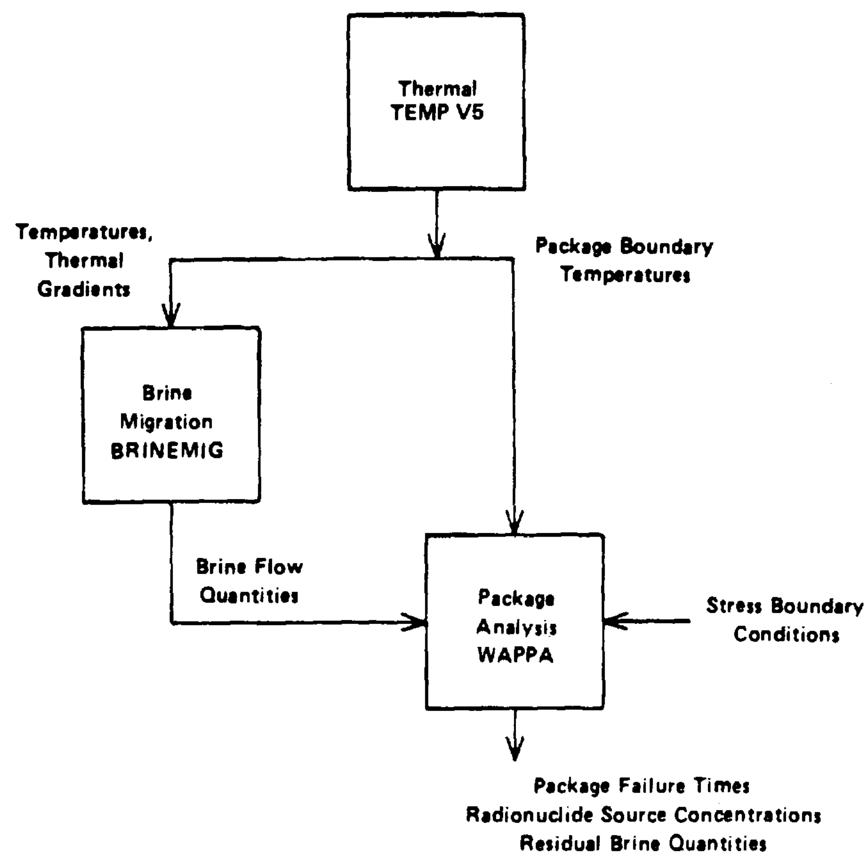
Analyses have assessed the expected performance of the engineered and natural barriers in a nuclear waste repository in Richton Dome. When possible, results of these analyses have been compared to NRC regulations and EPA standards. These analyses have considered both commercial high-level waste (CHLW) and spent fuel from pressurized water reactors (SFPWR).

Consideration of several interacting phenomena is required to assess the expected performance of an engineered barrier system in salt. These interactions are schematically depicted by Figure 6-4, which also indicates the specific codes that are used for the analyses discussed in this section. The WAPPA code (INTERA, 1983, ONWI-452) analyzes the interactions of several phenomena in addition to those shown in Figure 6-4. Figure 6-4 shows that package boundary temperatures are calculated by TEMPV5 (McNulty, 1985), a thermal code, and brine flow rates are estimated using BRINEMIG (McCauley and Raines, 1985). These data are used for calculation of corrosion and the other phenomena embodied in WAPPA. Package failure times and radionuclide source concentrations as calculated by WAPPA are compared with NRC regulations given in 10 CFR Part 60 and 40 CFR Part 191 standards for release to the accessible environment. If releases from the package are below 40 CFR Part 191 standards, then releases to the accessible environment are clearly below the standard. Radionuclide source concentrations are also made available for radionuclide transport calculations if needed. These preliminary analyses apply to a typical package located several packages away from the edge of the repository. Packages near the edge of a repository are subject to lower temperatures and smaller brine flow quantities and, consequently, should normally have longer life and lower releases of radionuclides.

Section 6.4.2.3.1 discusses thermal conditions that the Richton Dome repository will experience due to the emplacement of nuclear waste. Major factors that affect temperature levels, in addition to the waste package loading and spacing, are in situ temperature and thermal conductivity of the salt host rock. Section 6.4.2.3.2 shows that the in situ moisture content of salt and thermal gradients and temperatures around a waste package lead to a small amount of brine migrating toward each waste package.

Preliminary corrosion performance assessments in Section 6.4.2.3.3 show that the waste package is expected to last for longer than 10,000 years. However, even if an unexpected breaching of the waste package were to occur, Chambre et al. (1982) have found that the low solubility of container and overpack materials such as iron and of most nuclides, stagnant liquid films, and accumulated corrosion layers remaining in space previously occupied by the metal in the waste package will limit the nuclide release rate from the waste form. These factors, other than nuclide solubility, as discussed in the next paragraph, are not considered by this analysis. Hence, these factors add to the conservatism of the calculations. These factors will be the subject of study during site characterization.

Since no specific engineered barriers beyond the waste package are included in this preliminary analysis, releases from the waste package subsystem are compared to the NRC 10 CFR Part 60 requirements. Hypothetical nuclide releases are assumed between 300 and 10,000 years.



System Analyses for Assessment of Performance of Engineered Barriers

Figure 6-4

These hypothetical releases are larger than what is expected to actually occur because of consideration of factors discussed in the previous paragraph and are assumed to be limited only by the quantity of each nuclide that would dissolve into the quantity of brine available (Section 6.4.2.3.2). These calculations are discussed in Section 6.4.2.3.4. Additional data concerning solubilities will be obtained during site characterization.

Ground-water flow will be discussed in Section 6.4.2.3.5 regarding seal performance, an estimate of the extent of the disturbed zone, possible flow through host rock, and flow in aquifers. Ground-water travel times will be compared with 10 CFR Part 60 requirements. Additional data concerning ground-water flow will be obtained during site characterization.

6.4.2.3.1 Thermal Conditions. Preliminary thermal analyses using estimated thermal properties and geothermal gradients for the Richton Dome site provide time-dependent boundary temperatures for the waste package assessments in Sections 6.4.2.3.3 and 6.4.2.3.4 and radial profiles of temperature for the brine migration calculations in Section 6.4.2.3.2. Section 6.4.2.3.3 shows that temperatures have less impact on waste package performance than the in situ moisture content of salt. Table 6-29 and Figure 6-5 show that maximum expected surface temperatures on the waste package will reach 292 C (558 F) for commercial high level waste (CHLW) and 175 C (347 F) for spent fuel from a pressurized water reactor (SFPWR). This section discusses the analytical approach, data base and uncertainty, and results of the thermal analyses.

Analytical Approach. McNulty (1985) used the TEMPV5 code to estimate time-dependent temperatures around the waste package. The TEMPV5 code uses an analytical solution of finite line sources in an isotropic and infinite medium to model individual waste packages. Site-specific conditions may vary from these assumptions. The code uses linear superposition of temperature contributions from individual finite line sources as described by an analytical integration to calculate the temperature at a point. The TEMPV5 code allows either simultaneous emplacement of all waste as an infinite array of canisters or sequential emplacement of waste into various regions of the repository. This analysis assumes simultaneous emplacement in an infinite array. McNulty (1985) found that sequential emplacement has little effect on waste package surface temperatures. A transformation technique accounts for the dependence of thermal conductivity on temperature. TEMPV5 does not assume a homogeneous medium (a medium whose properties are constant throughout) because it allows thermal conductivity to vary with temperature throughout the infinite medium. The transformation does not account for the temperature dependence of diffusivity. However, McNulty (1985) shows that the temperature dependence of diffusivity has a small effect on computed temperatures.

Data Base and Uncertainties. The data used in the analyses consisted of thermal properties (Lagedrost and Capps, 1983, BMI/ONWI-522, Tables 20, 21, 22), waste package parameters (Westinghouse Electric Corporation, 1983, ONWI-438, Tables 1-2 and 1-3), and baseline repository inventory and design parameters (SCC, 1984a, Tables 5-1, -2, and -3). Uncertainty exists in thermal conductivities and ambient in situ temperature. Duffey (1980, SAND79-7050, pp. 3 through 7, and 59) and Wagner (1985, ONWI-300, p. 9) have observed lower thermal conductivities in the laboratory than in the field. Sampling disturbance of the kind reported by Lagedrost and Capps (1983, BMI/ONWI-522, p. 9) can reduce thermal conductivities measured in the laboratory. Consequently, Loken et al. (1984, Figure D-3) have suggested an increase of 40 percent in laboratory thermal conductivities as a correction. LETCo (1983, ONWI-289, p. 13) reports that a small uncertainty exists in the geothermal gradient. The geothermal gradient varies between 26 and 32 C (79 and 90 F) per kilometer (0.62 mile) for depths 300 to 3,400 meters (984 to 11,155 feet). LETCo (1983, ONWI-289, p. 39) reports an ambient in situ temperature of 50 C (122 F) for Richton Dome at the approximate planned repository depth. McNulty (1985) presents more details on the use of these and other data.

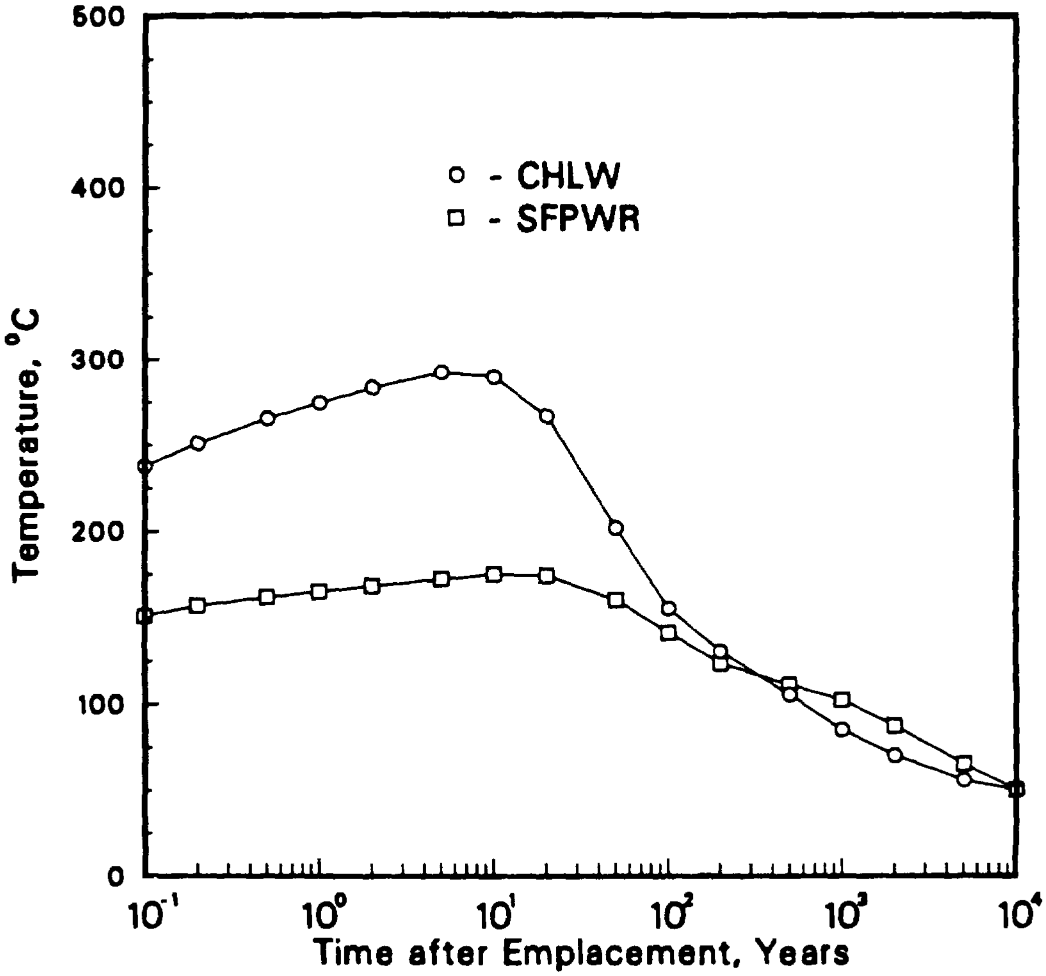
Thermal Analyses and Results. Separate thermal analyses were made for CHLW and SFPWR wastes. The McNulty (1985) calculations used an infinite array configuration for the layout of the waste packages. Figure 6-5 shows the time-dependent variation of temperature at the surface of the CHLW and SFPWR waste packages. Table 6-29 summarizes temperatures for both wastes as a function of time. This table indicates that expected maximum temperatures on the surface of a waste package would reach 292 C (558 F) for CHLW at 5 years and 175 C (347 F) for

Table 6-29. Infinite Array Temperatures from TEMPV5 Code at the Waste Package Surface for Richton Dome

Time (years)	Temperature, C	
	CHLW[a]	SFPWR[b]
0.1	237.8	151.2
0.2	251.0	157.2
0.5	265.3	162.0
1	274.5	165.0
2	283.2	168.0
5	292.2	172.1
10	289.5	174.8
20	266.5	173.8
50	201.6	159.9
100	155.0	141.0
200	130.3	123.3
500	105.2	110.9
1000	85.0	102.3
2000	70.1	87.4
5000	56.1	65.3
100000	50.1	50.6

Note: T_o = 50.1 C.

(a) Commercial high-level waste.
(b) Spent fuel from pressurized water reactors.



TEMPV5 Temperatures Versus Time at Salt-Overpack Interface for Richton Dome

Figure 6-5

SFPWR waste at 10 years. The temperatures reflect the combined effect of site-specific thermal conductivities and ambient in situ temperature. Uncertainty exists in the expected thermal conditions. However, waste package performance also depends on other factors such as the in situ moisture content of the salt. Section 6.4.2.3.3 shows that waste package performance depends more on brine migration than on any uncertainty in expected thermal conditions (see Jansen, 1985).

6.4.2.3.2 Fluid Conditions in Salt. Naturally occurring salt traps small brine inclusions within the salt crystals and along intercrystalline boundaries. When a thermal gradient is applied, solubility differences can cause the brine inclusions to migrate toward the heat source. Salt dissolves at the hot side of the inclusion, moves through the inclusion, and then precipitates at the cool side of the inclusion. When each inclusion reaches a crystal interface, intracrystalline brine migration stops. Intercrystalline movement may then occur along grain boundaries towards the heat source. This section discusses the preliminary analytical approach, data base and uncertainty, and results of the brine migration analyses.

Analytical Approach. McCauley and Raines (1985) used a finite difference code (BRINEMIG) to predict flow rates of brine migrating toward the waste package. BRINEMIG assumes the salt to have homogeneous and isotropic properties and uses the mass balance principle to calculate the moisture concentration profiles. The BRINEMIG code uses the empirical equation developed by Jenks and Claiborne (1981, ORNL-5818) to predict brine migration velocities due to a thermal gradient:

$$\log (V/G) = 0.00656\ T - 0.6036$$

where

V = velocity of brine migration, centimeters per year
G = thermal gradient, degrees C per centimeter
T = temperature, degrees C.

Jenks and Claiborne (1981, ORNL-5818, Figure 6) used available data to derive the above equation on intracrystalline brine migration to overpredict brine migration due to a thermal gradient. Additional work is required to understand the role of intercrystalline brine flow in the overall process of brine migration. McCauley and Raines (1985) show that BRINEMIG gives brine accumulations that show reasonable agreement with those from the Salt Block II experiment (Hohlfelder, 1980, SAND79-2226). This comparison suggests that BRINEMIG will reasonably predict brine flows even though the code does not consider the brine movement along grain boundaries. Because theoretical considerations (Anthony and Cline, 1971, p. 3380) indicate the existence of a threshold thermal gradient below which brine does not migrate, the analyses also considered cases with and without a threshold gradient. More work is planned on this phenomenon during site characterization.

Data Base and Uncertainty. The amount of brine that flows toward the waste package is directly proportional to the initial brine content of the salt. Knauth and Kumar (1981) found water contents of 0.0001 to 0.007 weight percent in salt from Rayburn's and Vacherie Domes (Louisiana). Gevantman (1981, Table 1.4) reports brine contents between 0.01 and 0.02 weight percent for Avery Island Dome salt and 0.004 and 0.040 weight percent for Weeks Island Dome salt. Site-specific water content data are not available for Richton Dome salt; however, Roedder and Chou (1982, pp. 2-8) suggest that a water content of 0.1 weight percent is a conservatively high value for domal salts. Using conservative assumptions regarding the expansion of water upon saturation with halite and thermal expansion at 90 C (194 F) 0.1 weight percent water is equivalent to 0.26 volume percent brine (Section 3.2.7.4). To assure that brine migration quantities are not underpredicted, the calculations assumed an initial water content of 0.5 volume percent.

These preliminary calculations used thermal threshold gradients of 0.125 and 0 C (0.225 and 0 F) per centimeter. Jenks and Claiborne (1981, ORNL-5818, pp. 96-103) used 0.125 C (0.225 F) per centimeter for temperatures below 100 C (212 F). A zero thermal threshold gradient gives higher estimates of brine flow to the waste package.

Brine Migration Analyses and Results. BRINEMIG calculates brine flow rates from radial temperature profiles given at various times. BRINEMIG uses temperatures and thermal gradients interpolated from these profiles in the equation developed by Jenks and Claiborne (1981, ORNL-5818). The TEMPV5 code (McNulty, 1985) supplies the temperature profiles to BRINEMIG in tabular form. Figures 6-6 and 6-7 present radial temperature profiles calculated by TEMPV5 for CHLW and SFPWR, respectively. Figure 6-6 shows that CHLW has the steepest thermal gradients. Figures 6-8 and 6-9 present brine accumulation at the waste package with time for threshold gradients of 0.125 and 0 C (0.225 and 0 F) per centimeter, the expected and extreme cases, respectively. With the threshold gradient, CHLW and SFPWR produce 0.17 and 0.082 cubic meter (6.0 and 2.9 cubic feet), respectively, of brine at the waste package. Without a threshold gradient, CHLW and SFPWR produce 0.18 cubic meter and 0.14 cubic meter (6.3 and 4.9 cubic feet) of brine, respectively. A threshold gradient reduces the predicted brine accumulation, especially for SFPWR where temperatures remain high for a much longer time, as shown by comparing Figures 6-6 and 6-7. Jansen (1985) and the description in Section 6.4.2.3.3 show that these differences in the accumulated brine do not significantly impact the performance of the waste package.

Other Sources of Water. Internal sources of water known to occur in some salt domes are described in Section 3.3.2.1.3. In general, water occurrences in salt domes are small in size and are isolated from ground-water systems outside the dome.

Another possible source of water is the intrusion of ground water from an aquifer in the unexpected event of an intrusion scenario. Such waters would probably become completely saturated with Na^+ and Cl^- prior to reaching the repository level. Some of the calculations in Section 6.4.2.3.3, Waste Package Performance, consider unlimited flow quantities of "intrusion" brine to give an idea of the effect this source of water would have on package life.

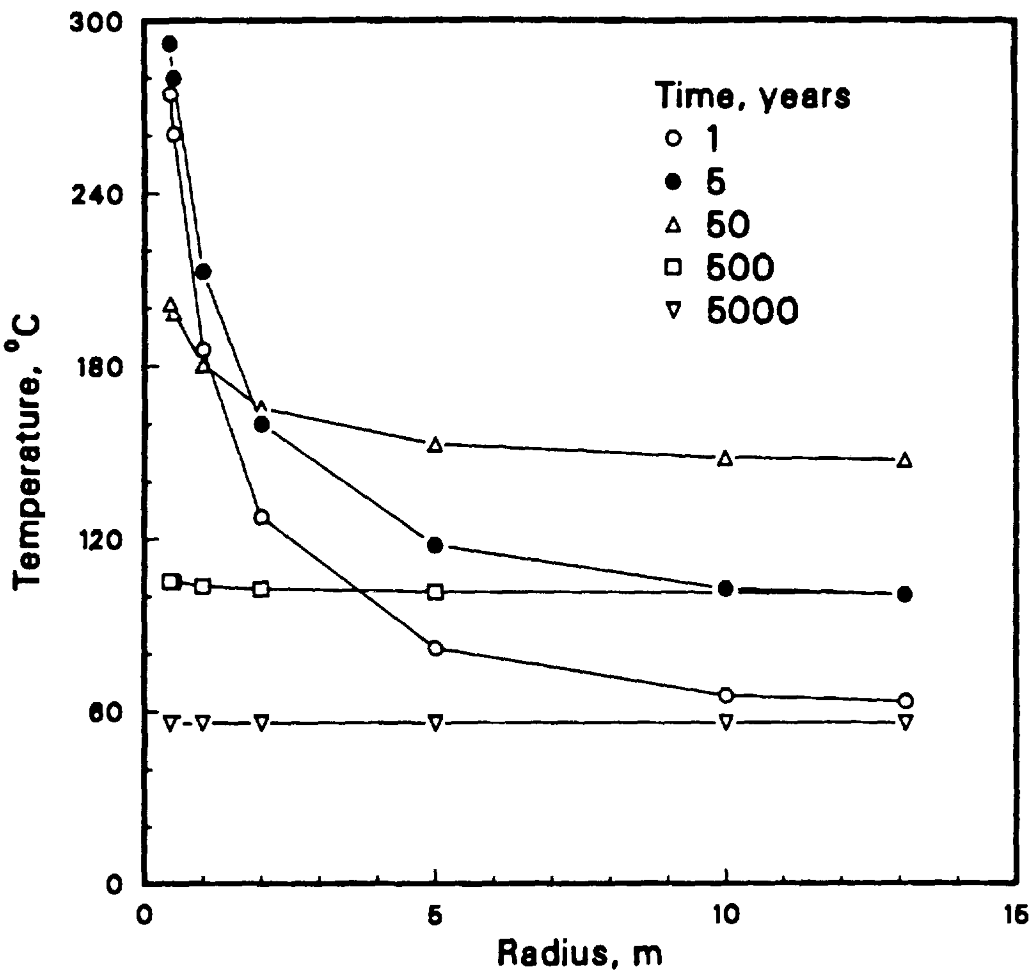
Sources of water will be investigated in more detail during site characterization.

6.4.2.3.3 Waste Package Performance. A preliminary performance assessment of waste package designs was conducted with the WAPPA waste package code (Jansen et al., 1984; Jansen, 1985; INTERA, 1983, ONWI-452). Expected conditions for temperature, stress, brine composition, radiation level, and brine flow rate were used as boundary conditions to compute expected corrosion of a thick-walled container of low carbon steel. The waste package failure calculation was essentially a one-dimensional radial geometry integration of corrosion rates uniformly distributed over the outside of the container wall but varying with temperature over a 10,000-year history of the waste package. Package failure was assumed to occur when the corrosion allowance was exceeded and the package was assumed to yield under lithostatic pressure.

Boundary Conditions at the Package Surface. Boundary conditions for temperature, brine flow rate, stress, radiation level, and brine composition at the overpack surface, which are needed by the WAPPA code for the package failure analysis, were estimated by the following methods:

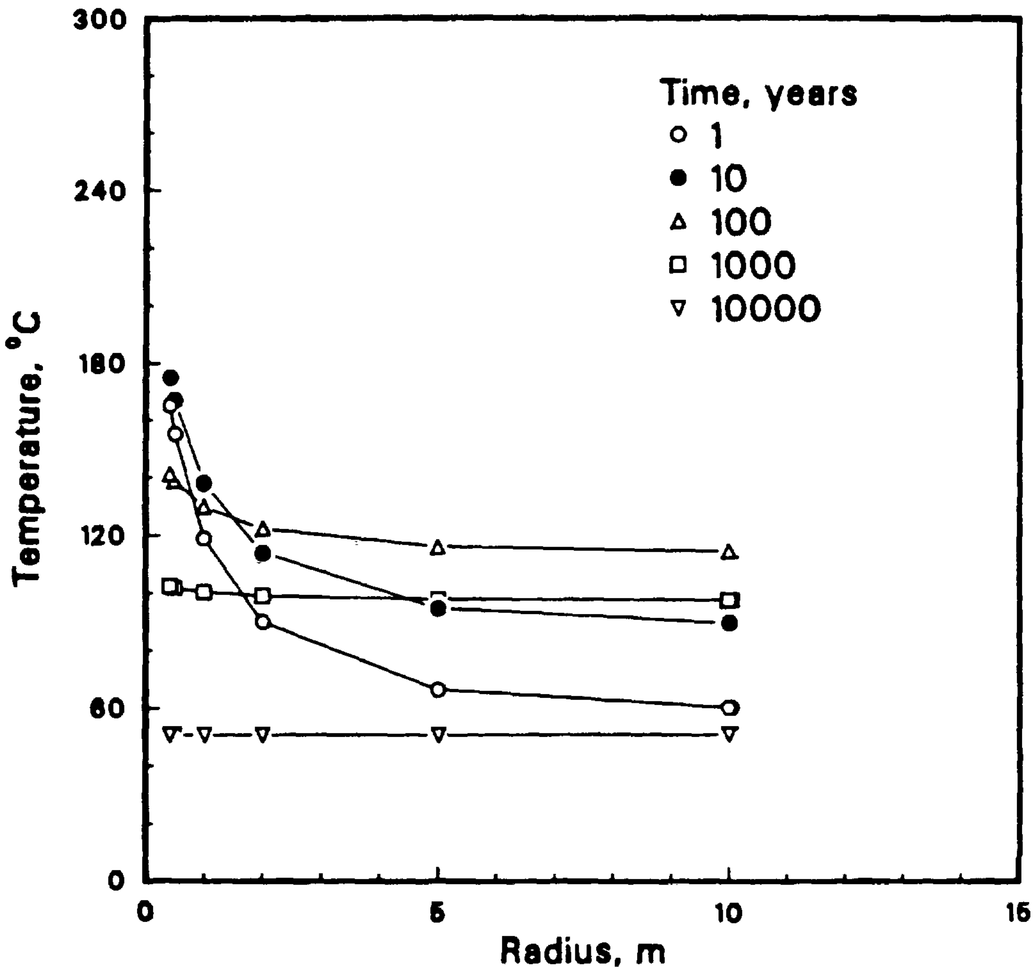
1. Temperature. The temperatures at the surface of the waste package were computed by the TEMPV5 code (based on analytical solutions for decaying short line sources) and were discussed in Section 6.4.2.3.1. The maximum temperatures were 292 C (558 F) at 5 years for the CHLW package surface and 175 C (347 F) at 10 years for SFPWR.

2. Brine Flow Rate. Computation of the accumulation of brine flowing to the waste package was discussed in Section 6.4.2.3.2. The brine inflow rates shown in Figure 6-10 were provided as input from BRINEMIG and are needed to account properly for the water in the brine consumed by chemical reaction with the steel overpack at each time step in the computation process. The corrosion reaction stoichiometry consumes the water in 0.32 cubic meter of brine and produces 400 cubic meters of hydrogen gas per centimeter of steel container thickness dissolved. Corrosion calculations were carried out for three brine conditions: (1) brine migration with a thermal gradient flow cutoff (the expected condition), (2) brine migration with no thermal gradient flow cutoff, and (3) corrosion with an unlimited excess of brine.



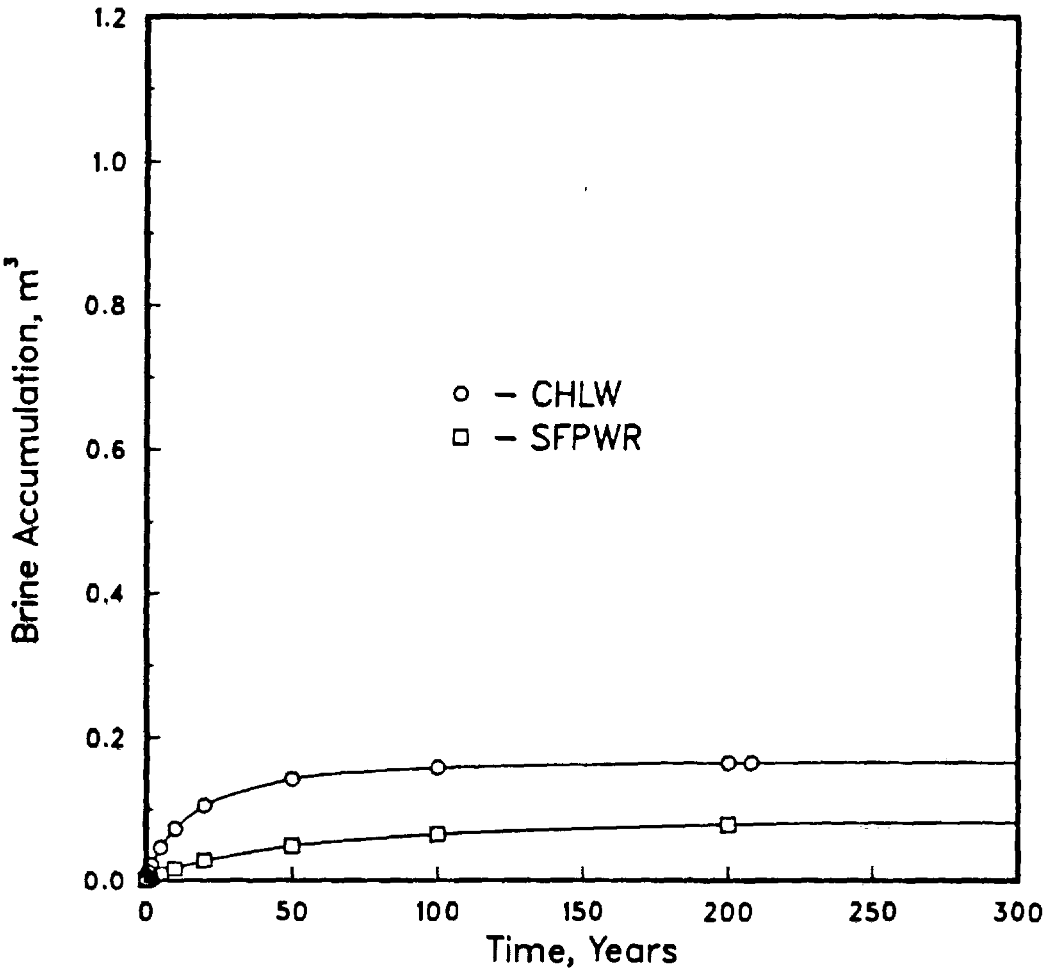
Temperatures Around CHLW Waste Package at Richton Dome

Figure 6-6



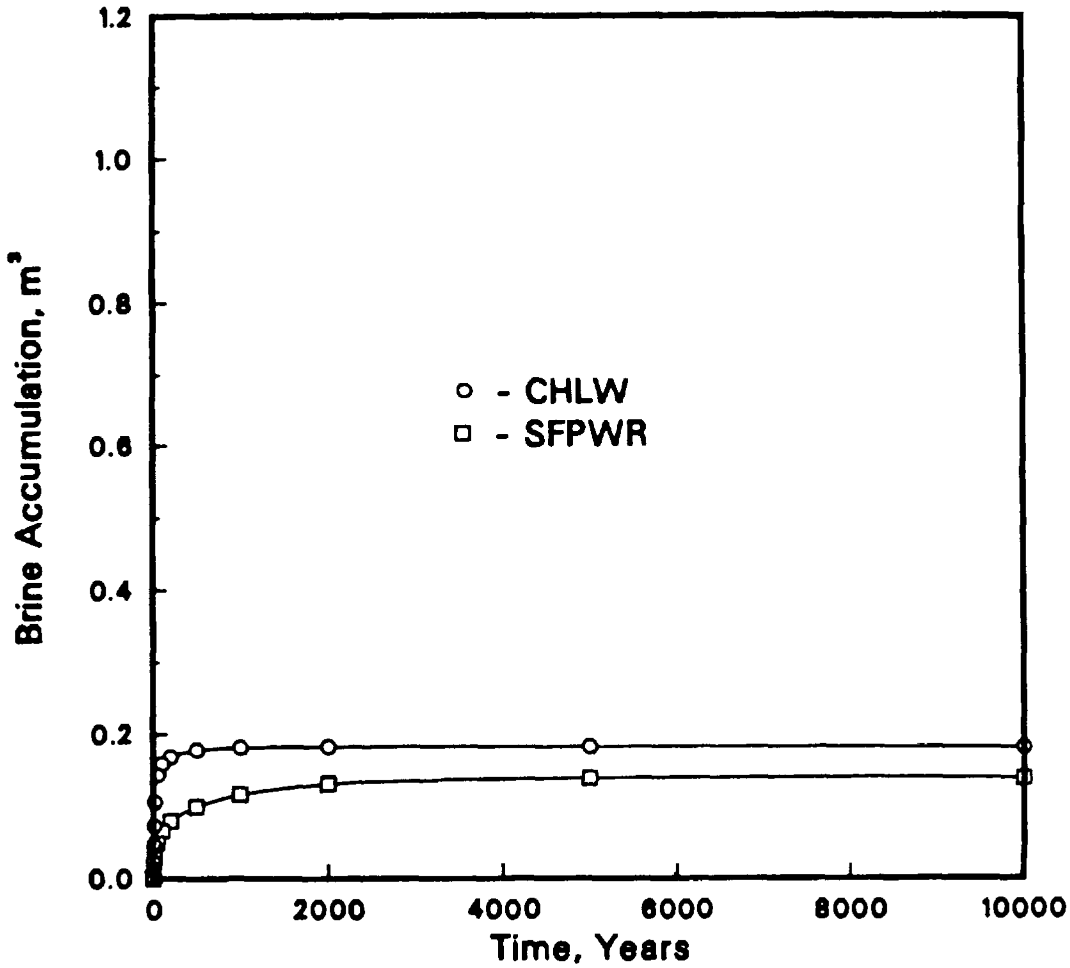
Temperatures Around SFPWR Waste Package at Richton Dome

Figure 6-7



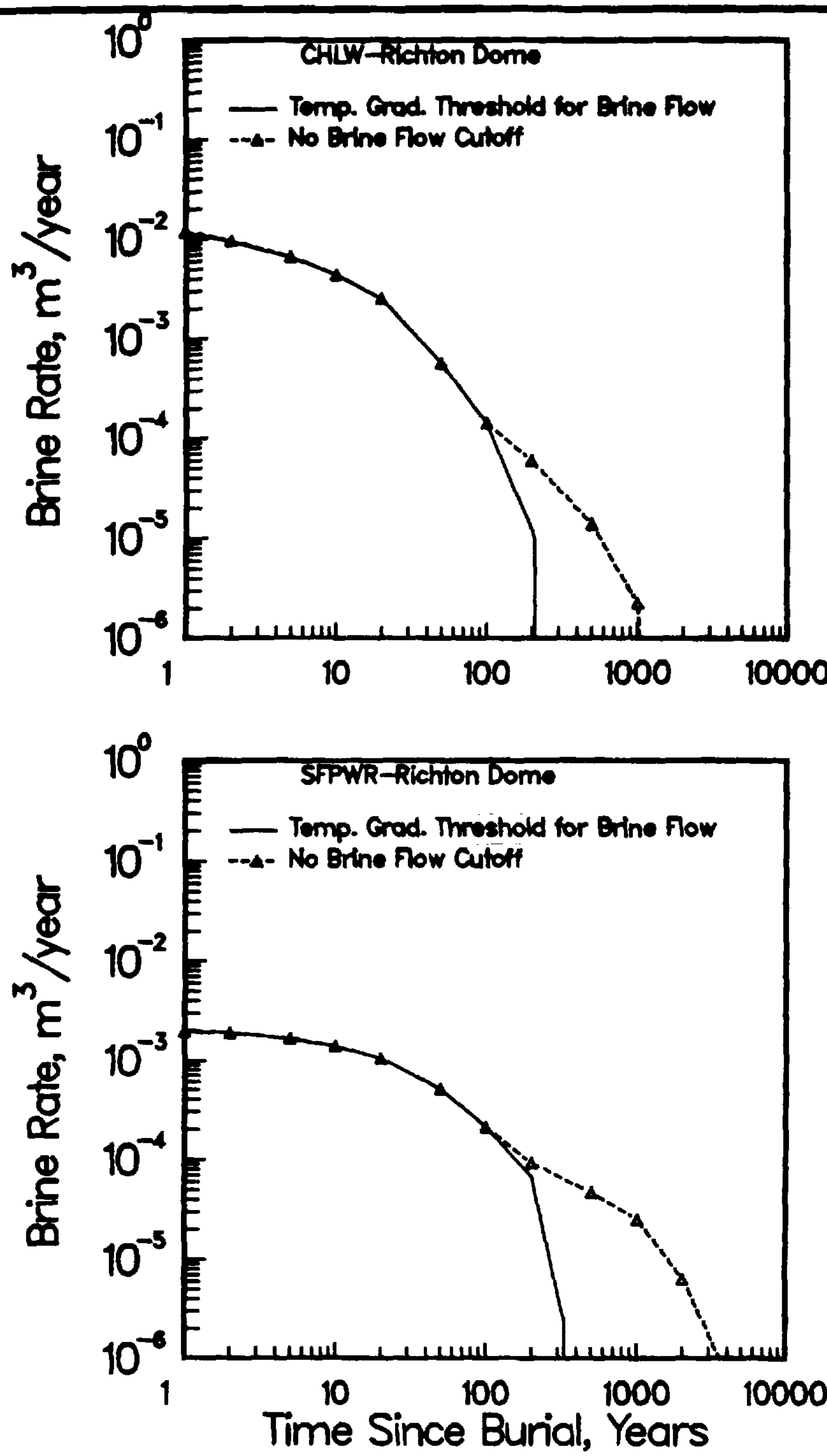
Brine Accumulation at Waste Package With Time and Zero Threshold Gradient of 0.125 °C/cm for Richton Dome

Figure 6-8



Brine Accumulation at Waste Package With Time and Zero Threshold Gradient for Richton Dome

Figure 6-9



Brine Migration Inflow Rates per Canister

Source: Jansen, 1985

Figure 6-10

The maximum gross accumulated brine volumes (i.e., without chemical reaction) with a thermal gradient cutoff were about 0.17 cubic meter for the CHLW package and about 0.082 cubic meter for the SFPWR package. With no brine flow cutoff, the maximum gross accumulated brine volumes as summed by WAPPA reached 0.18 cubic meter at 10,000 years for the CHLW package and 0.15 cubic meter for the SFPWR package. These values are insignificantly different from the accumulated volumes reported in the previous section because the WAPPA sum uses a different algorithm than BRINEMIG. For corrosion computations, the brine flow was assumed to be uniformly distributed around the radial perimeter and along the length of the overpack.

3. Brine Composition. Because dome salt is generally very pure, the composition of the thermally migrating brine (i.e., salt inclusion brine) that contacts the package at Richton Dome is expected to be of low magnesium content. This brine composition is also typical of salt dissolution brines used for unexpected events such as brine intrusion scenarios. High magnesium brines are not expected at the dome site because (1) highly soluble magnesium-bearing evaporite minerals, such as carnallite and kieserite, have not been identified in either the host rock or adjacent sediments; and (2) the small concentrations of dolomite present are not expected to be a significant magnesium source, as the solubility of dolomite is extremely low (Stumm and Morgan, 1970, p. 194). The corrosion tests that have been run to date (Kreiter, 1984, PNL-4250-4) have used Permian Basin No. 2 brine as a low-magnesium-content brine. Permian Basin No. 2 brine is a modification of the low-temperature-salt-dissolution brine (Permian Basin No. 1) that has been equilibrated at 150 C (302 F) (representative repository conditions) to precipitate anhydrite, which would otherwise have formed a protective scale on the specimen surfaces during the tests. Compositions of both brines are shown in Table 6-30 (Kreiter, 1984, PNL-4250-4).

4. The Radiation Field. The ANISN-W code (ORNL and Westinghouse, 1973) with 18 energy source groups and the DLC-23 cross section library (ORNL and SAI, 1973), assuming the small neutron dose effects to be negligible, were used to compute radiation fields in and near the package (Figure 6-11) from gamma energy source terms (Jansen 1985) that had been computed by the ORIGEN2 code (Croff, 1980, ORNL-5621). The normalized dose rate profile was found to be invariant with time and decayed at precisely the same rate as the total photon rate. This normalized profile and the transient total photon rate were then used directly in the WAPPA code to compute local dose rates at any time. WAPPA made semilogarithmic interpolations of the radiation field in the container wall (Figure 6-12) to estimate the dose at intermediate wall thicknesses. The dose rate at the salt-container interface of the SFPWR package is initially 32 rads per hour and is 21 rads per hour at the CHLW package surface (Figure 6-13). Both fields decay tenfold during the first 100 years, but the SFPWR radiation field contains more long-lived actinides. It is clear from Figure 6-14 that any radiation field below several hundred rads per hour should not produce a significant effect on the corrosion rate unless highly energy-dependent radiation damage effects to salt prove to be more significant than current estimates (Levy, 1983). This observation must be tempered by the fact that if appreciable corrosion penetrates deep into the overpack very rapidly (this is not present at expected uniform corrosion conditions), then the radiation field will be much higher than at the uncorroded surface, and its exact value there may be high enough to require more reliable estimates of the radiation field.

5. Corrosion Rates. Corrosion rates of low carbon steel are dependent on temperature, brine composition, and radiation level. The estimates made by R. E. Westerman of Pacific Northwest Laboratory (PNL) from preliminary data (Kreiter, 1984, PNL-4250-4) were correlated and extrapolated (Jansen, 1985) as shown in Figure 6-14. Data now available (Westerman et al., 1983 PNL-SA-1173) differ only in detail. A quotation from Westerman describing the estimates follows:

   "The supplied values were estimated on the basis of the limited corrosion rate data presently available (07/21/83). These data have been primarily obtained in mild and low-alloy steels and nodular cast irons in simulated Permian Basin

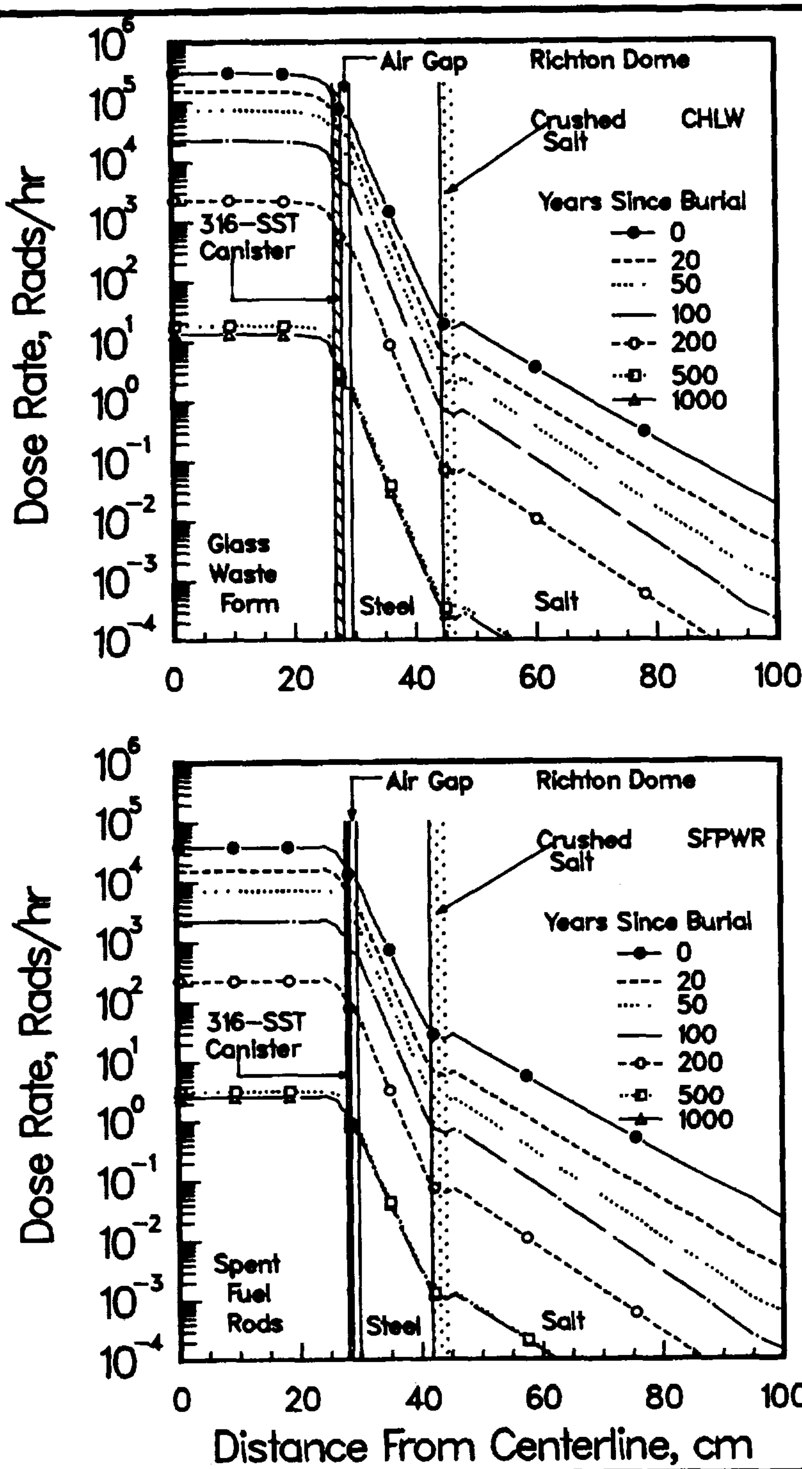
Table 6-30. Compositions of Simulated Low-Magnesium-Content Salt Brines Used in Corrosion Tests[a]

Ion Concentration grams per cubic meter

Ion	Low Magnesium Content Brines	
	Permian Basin No. 1[b]	Permian Basin No. 2[b]
Na^+	123,000	123,000
Ca^{2+}	1,560	1,100
Mg^{2+}	134	122
K^+	39	39
Sr^{2+}	35	35
Zn^{2+}	7.8	7.9
Cl^-	191,000	191,000
SO_4^{2-}	3,200	1,910
HCO_3^-	30	23
Br^-	32	24
F^-	1.1	1.0
pH	7.2	7.05

(a) Considered representative of Richton Dome thermally migrating brines and salt dissolution brines.

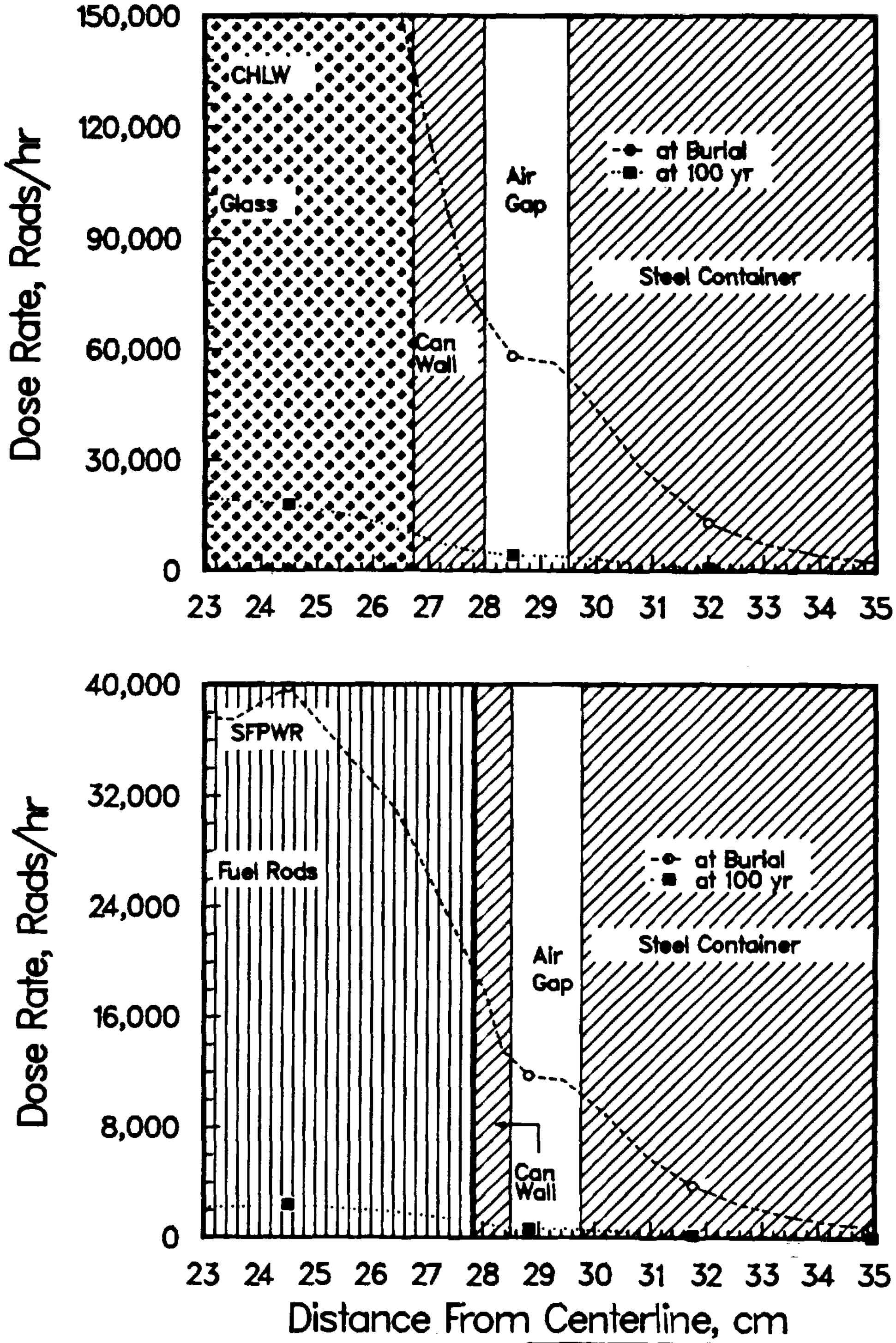
(b) Attempts to conduct corrosion experiments with Permian Basin No. 1 brine led to the precipitation of protective anhydrite coatings on specimen surfaces, so the Permian Basin No. 1 brine was heated to operating temperatures (150 C) to equilibrate and precipitate anhydrite and was renamed Permian Basin No. 2 before using it in corrosion tests.



Source: Jensen, 1985.

Radiation Fields at Waste Package Material Interface

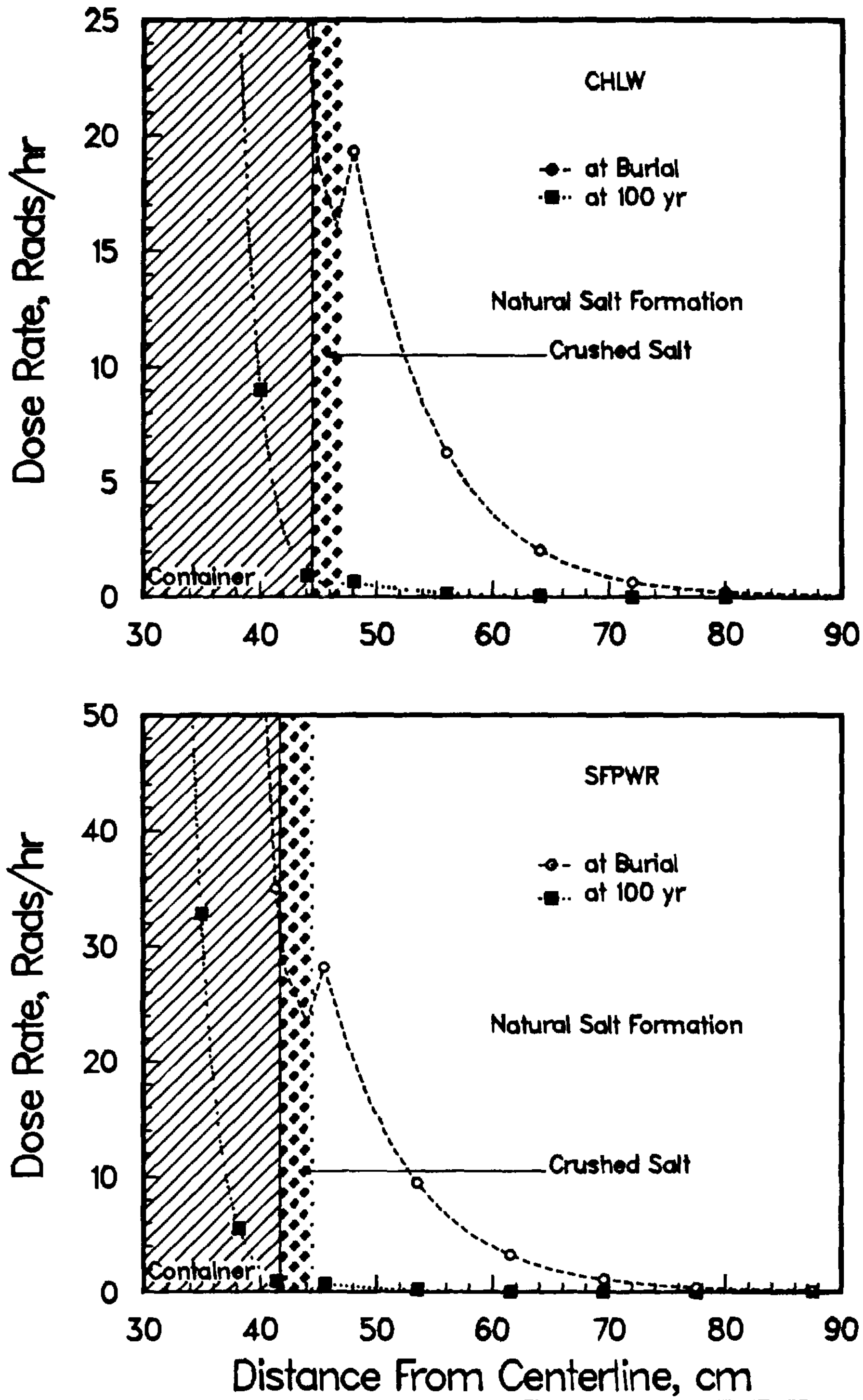
Figure 6-11



Radiation Fields at Waste Form—Container Interface

Figure 6-12

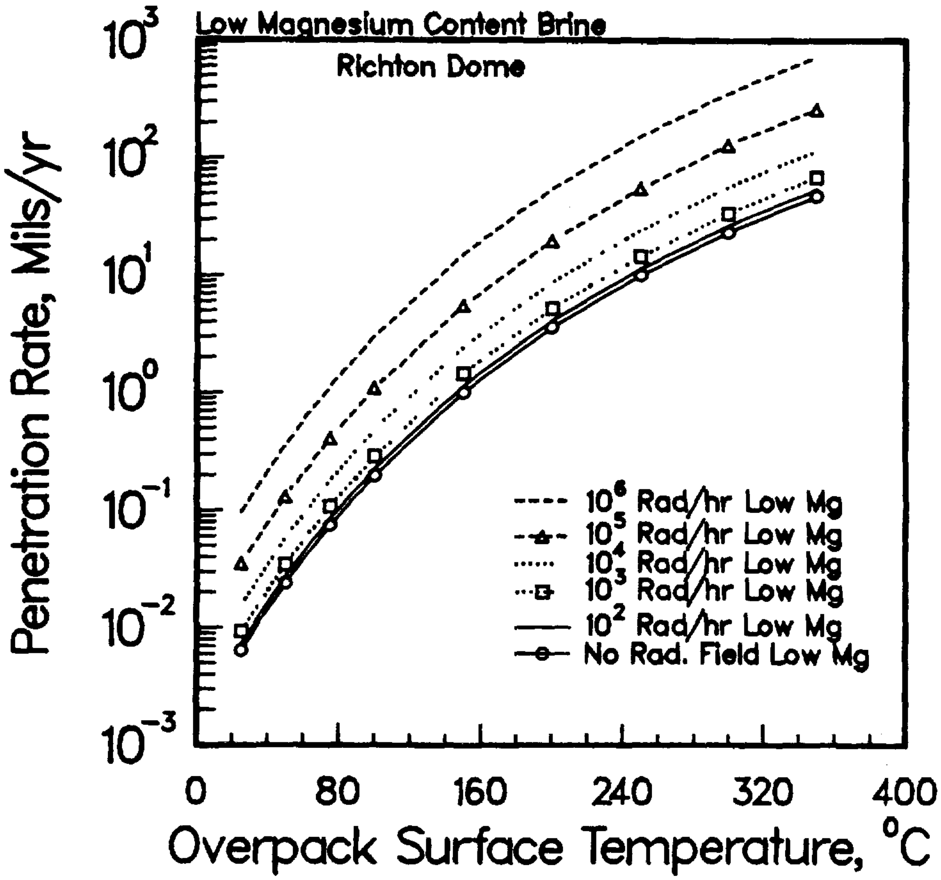
Source: Jansen, 1985



Radiation Fields at Container Crushed Salt Interface

Figure 6-13

Source: Jansen, 1985.



Effect of Radiation Field on Corrosion Rates of Low Carbon Steel Container in Brines

Figure 6-14

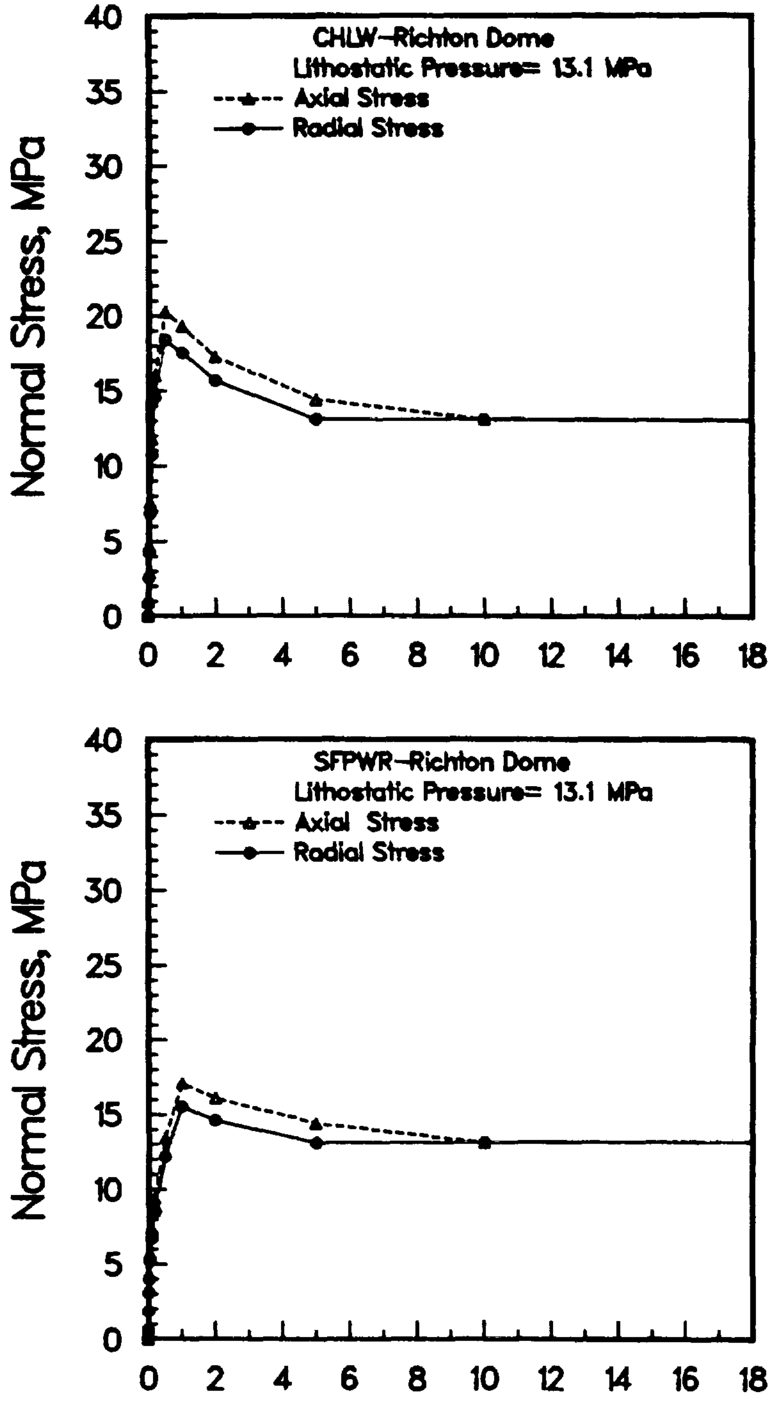
Source: Jansen, 1985

intrusion brine at 150 C in irradiated and unirradiated tests in flowing autoclave systems (PNL work), and in unirradiated Brine A at 250 C in static autoclave systems (PNL and Sandia work). The data on irradiated simulated intrusion brine at 250 C and irradiated Brine A amount to only a few very short-term tests (Sandia work). Because of the uncertainties involved in estimating corrosion rates without a clear understanding of the effects of the independent test variables mentioned (temperature, brine composition, irradiation intensity) on the rate-limiting mechanism(s) of the corrosion process, the estimated values in the table may be in error by as much as a factor of five, with the highest degree of uncertainty in the 250 C and high irradiation-intensity regimes."

The reference corrosion rate was 0.025 millimeter (0.001 inch) per year at 150 C (302 F) for the low magnesium brine, and the temperature effect was introduced by a free energy of 10.1 kilocalories per mole. Intermediate oxidizing species that may control the corrosion rate were found to vary with the square root of the dose rate in preliminary computer modeling activities (Kreiter, 1984, PNL-4250-4). Therefore, the effect of radiation on corrosion was derived by fitting an apparent square root dependency to the corrosion data. The same radiation enhancement factor for corrosion, which produces about a twentyfold increase in corrosion rate at 10^6 rads per hour, was applied at all temperatures. For expected dose rates at container outer surfaces of 20 to 40 rads per hour, the increase is negligible.

6. Boundary Stresses. Creeping of the salt is expected to close the borehole around the waste package during the first year. Maximum normal stress due to thermal gradients may be exerted on the package during the first year or two after burial, with a gradual decay to lithostatic pressure during the first decade after burial. The peak values and the decay histories of the stresses are currently poorly defined. An analysis of similar behavior at the Asse salt dome in Germany showed the stresses to be always compressive and verified a creep law model for repository conditions in that salt (Prij and Vons, 1984). For the purpose of this preliminary analysis, a 25 percent excess horizontal (radial) compressive stress and a 35 percent excess vertical axial compressive stress (Figure 6-15) have been assumed relative to the lithostatic pressure, peaking near 1 year after burial (Loken et al., 1984). Also, it has been assumed that the 5.0-centimeter (2.0-inch) CHLW and 2.5-centimeter (1.0-inch) SFPWR allowances for overpack corrosion used by Westinghouse Electric Corporation (1983, ONWI-438) apply at the long-term lithostatic pressure in the salt formation. The mechanical submodel was not used in the WAPPA code for stress calculations. Instead, when the uniformly corroded thickness reached these values, it was assumed that the overpack would yield and the barriers would breach, allowing brine to contact the waste form.

Failure of Waste Packages. A waste package has not actually failed until radionuclides are transmitted outward past the waste package boundary. The process is initiated by the in-migration of brine and the onset of corrosion of the overpack. This process chemically consumes oxygen from the water in the brine. If and when all the oxygen is consumed, the process stops. Even if corrosion persists until the overpack is penetrated, additional barriers exist in the form of the stainless steel canister and Zircaloy clad for SF and the waste form itself for CHLW. Even though the clad may not be intact and stainless steel is not especially tolerant of salt brines, zirconium and iron tend to oxidize readily and further consume oxygen to help ensure anoxic conditions in any brine that might remain unreacted. In addition, these materials and their corrosion products physically retard the movement of fluids toward the interior of the waste package and thus further inhibit the release of radionuclides. Furthermore, brine must dissolve the fuel pellet (for SF) or the glass (for CHLW) along with the radionuclide elements. As will be discussed later, many nuclide elements have low inherent solubilities and, therefore, matrix solubility is not an important factor. However, others (e.g., cesium, iodine) do not have inherently restrictive elemental solubilities but are significantly retarded by considerations of matrix solubility. None of these factors is considered in this preliminary analysis.



Stress Boundary Conditions at Waste Package Midplane

Figure 6-15

Source: Jansen, 1985

In addition to the conservative factors above being ignored, the distribution of failure times of waste packages would spread releases over time (perhaps periods longer than 10,000 years). For purposes of this preliminary analysis, all waste packages are assumed to fail simultaneously at the calculated time at which the portion of the overpack that is allocated for a corrosion allowance is corroded away.

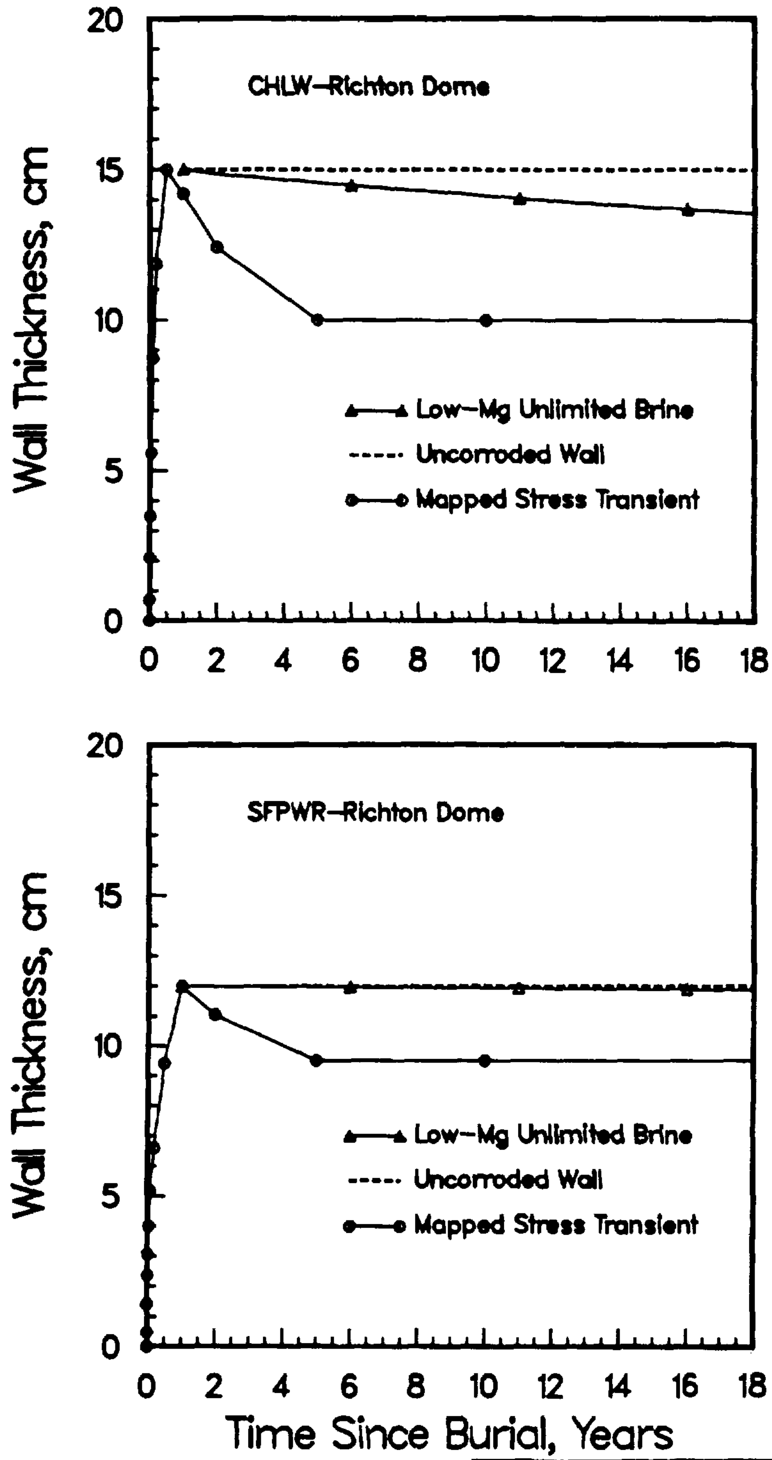
Corrosion and Failure of the Overpack. Corrosion of the overpack with unlimited brine flow quantities during the first 20 years is compared in Figure 6-16 with the estimated wall thickness at which the overpack would yield. The difference between lithostatic and maximum failure thicknesses has been normalized to equal the corrosion allowance. The effect of the stress transient (Figure 6-16) is negligible by the time corrosion becomes appreciable for both CHLW and SFPWR packages. Thus, if the package is designed to withstand the early high stresses prior to the occurrence of significant corrosion without a corrosion allowance, a detailed analysis of transient stresses is not necessary in the WAPPA code calculation.

At longer times, different results are produced for thermal-gradient-driven inflowing brine (the expected condition at Richton Dome) than with an unlimited amount of brine available (Figure 6-17 and Table 6-31). Numerous corrosion mechanisms exist, e.g., uniform corrosion, stress corrosion cracking, pitting, and intergranular attack. Low carbon steel, the material selected for the overpack, is not especially susceptible to pitting and other nonuniform corrosion phenomena as confirmed by corrosion experiments (Kreiter, 1984, PNL-4250-4; Westerman et al., 1983, PNL-SA-11713). The brine is expected to distribute uniformly over the package surface because of the crushed salt backfill. If the brine does distribute uniformly over the overpack surface, the analyses indicate that brine corrodes only 0.54 centimeter (0.2 inch) of the 5.0-centimeter (2.0-inch) corrosion allowance for CHLW and 0.28 centimeter (0.1 inch) of the 2.5-centimeter (1.0-inch) corrosion allowance for SFPWR. The analyses further indicate that corrosion would then stop indefinitely because no more water would be available to react with the remaining iron in the overpack.

Corrosion of the waste package in unlimited quantities of intrusion brine is also shown in Figure 6-17 and Table 6-31. This approximates the condition that might occur in the event of an intrusion scenario. With uniform corrosion rates, the CHLW package is intact at 10,000 years. The SFPWR overpack is estimated to fail at 4,800 years under these intrusion conditions.

Note that Kumar and Martinez (1981) report the presence of higher-magnesium leak brines from the Belle Isle and Weeks Island salt mines of Louisiana. Based on the analysis of 110 samples, magnesium concentrations ranging from approximately 10 to 25,000 milligrams per liter were observed. Jansen (1985, Table 4b) evaluated waste package corrosion for limited quantities (0.5 volume percent) of thermally migrating, high-magnesium brines (35,000 milligrams per liter) for the Richton Dome site and concluded that both CHLW and SFPWR waste packages would be intact at 10,000 years. Thus, the presence of high-magnesium thermally migrating brines at Richton Dome is not expected to adversely affect waste package performance. The presence of high-magnesium intrusion brines is considered to be highly unlikely because (1) soluble, magnesium-bearing evaporite minerals such as carnallite, kieserite, and polyhalite do not appear to be present; and (2) dolomite is present in trace quantities, but the aqueous solubility of dolomite is very low. In fact intrusion brines of any type are considered unlikely at the domal site because the intrusion brine scenario requires a hydrological conduit for the migration of unlimited volumes of brine to the waste package surface. Any mechanism for the formation of such a conduit requires one or more catastrophic, and therefore unlikely, events.

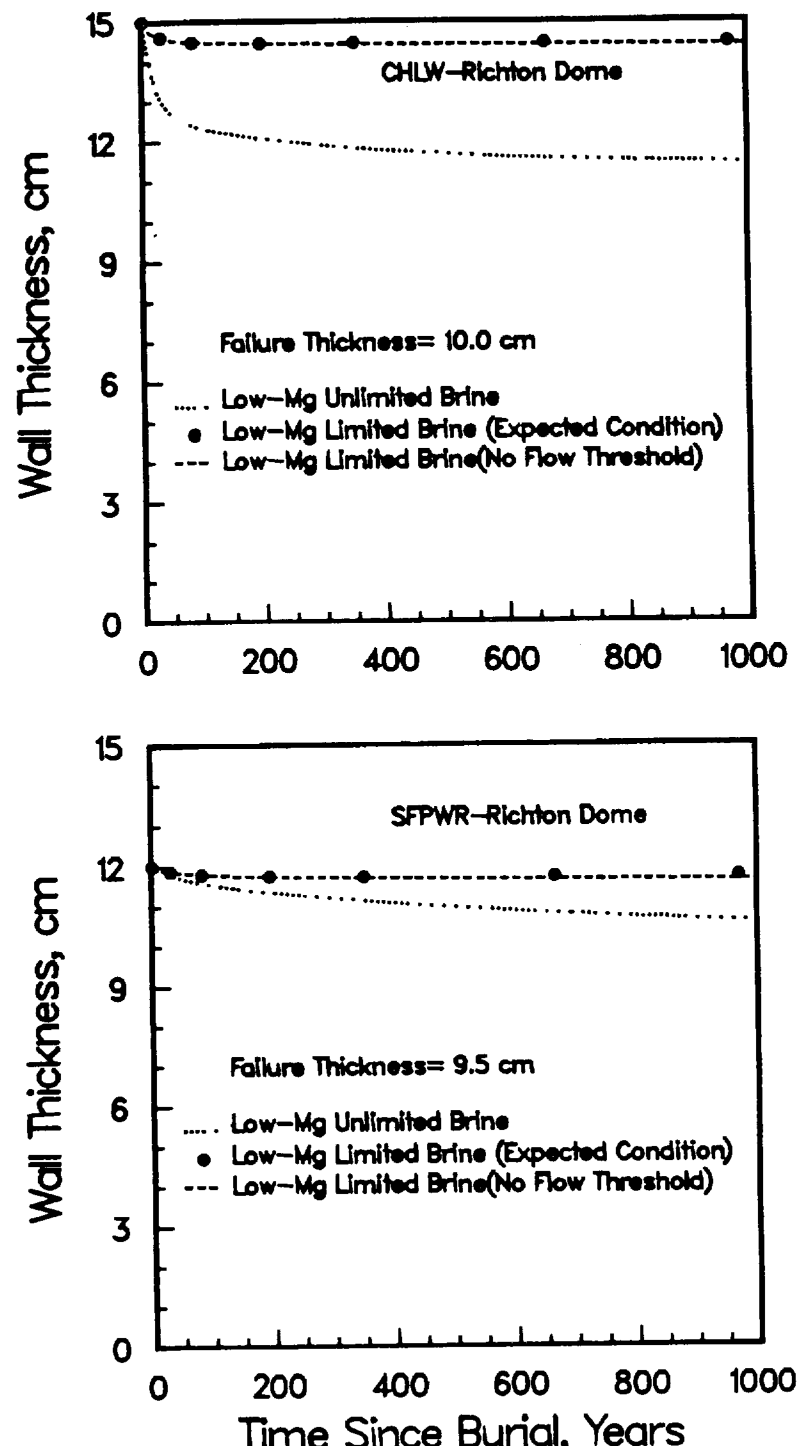
With the low corrosion rates in low-magnesium brine, the results for expected conditions for the Richton Dome site are not very sensitive to nonuniform distribution of limited quantities of brine over the package surface. A measure of the sensitivity of the uniform brine distribution results to nonuniformity of brine distribution is the fraction of coverage of the overpack surface by the limited amount of brine at which the available water is just sufficient to permit uniform corrosion of the complete corrosion allowance. With surface coverages less than this critical value, the corrosion rate is governed only by the chemical reaction rate. The critical percentage surface coverage for the Richton Dome site is zero for CHLW



Source: Jansen, 1985

Comparison of Corrosion With Transient Failure Thickness of Container

Figure 6-16



Source: Jansen, 1985

Effect of Brine Rate on Corrosion of the Container

Figure 6-17

Table 6-31. Effect of Brine Availability on Failure of Waste Packages in Richton Dome

Corrosion Conditions	Uniformly Corroded Thickness, cm	Failure Time,[a] year	Condition at 10,000 year
CHLW	EXPECTED CONDITION - THERMALLY MIGRATING BRINE		
Low-Mg, Limited Brine Volume	0.54	(b)	Intact
	UNEXPECTED CONDITIONS - THERMALLY MIGRATING BRINE		
Low-Mg, Limited Brine Volume (no brine flow threshold)	0.60	(b)	Intact
	UNEXPECTED CONDITIONS - INTRUSIVE SALT DISSOLUTION BRINE		
Low-Mg, Unlimited Brine Volume	4.5	greater than 10,000	Intact
SFPWR	EXPECTED CONDITION - THERMALLY MIGRATING BRINE		
Low-Mg, Limited Brine Volume	0.28	(b)	Intact
	UNEXPECTED CONDITIONS - THERMALLY MIGRATING BRINE		
Low-Mg, Limited Brine Volume (no brine flow threshold)	0.47	(b)	Intact
	UNEXPECTED CONDITIONS - INTRUSIVE SALT DISSOLUTION BRINE		
Low-Mg, Unlimited Brine Volume	2.5	4,800	Failed

(a) "Failed" means that a thickness equal to the corrosion allowance has been corroded uniformly. "Failure Time" is the time that this occurrence takes place.

(b) Failure is not ever expected under these conditions.

(meaning no effect of uniformity of surface coverage by brine) and 11 percent for SFPWR. Thus, any surface coverage less than 11 percent would shorten the package lifetime for SFPWR containers. Emplacement procedures, such as the oversize of the borehole, whether it is backfilled, the void space in the crushed salt backfill, and the water content of the backfill and of the salt formation itself, are expected to affect the uniformity of brine distribution over the package surface.

Only uniform corrosion has been reported in the overpack material tests at saturated anoxic conditions (Kreiter, 1984, PNL-4250-4; Westerman et al., 1983, PNL-SA-1173). However, although perfectly uniform corrosion is a useful concept, it is a theoretical limit. Some nonuniform corrosion occurs even in the most nearly uniformly corroded specimens. Limits will eventually be obtained from test programs for the degree of nonuniformity of the attack of brine upon the overpack material under expected conditions. At the present time we can only make parametric analytical studies of the hypothetical effect of pitting ratio* on the waste package integrity.

For small pitting ratios, the pit does not penetrate through the corrosion allowance of the container before corrosion is halted by lack of water availability or before the 10,000-year computation period is exceeded. For larger pitting ratios the pit penetrates the corrosion allowance thickness in a shorter time than uniform corrosion and the overpack is then assumed to fail mechanically, breaching the container and permitting radionuclides to be leached from the waste form through the breach. At some pitting ratio designated here as the critical value, the pit penetrates the corrosion allowance at exactly 10,000 years. This then becomes a measure of how sensitive the uniform corrosion results would be to pitting or crevice corrosion if one or the other occurred. This is a very conservative assumption. In fact, this mechanical failure may never occur, and it may be necessary for a pit to penetrate through the entire container wall thickness to permit brine to contact the waste form.

For the Richton Dome site, at the expected conditions for thermally migrating brine, the critical pitting ratio is 9 for both CHLW and SFPWR. This ratio indicates a low sensitivity of computation results to nonuniform corrosion. On the other hand, for the unlimited volume of low-magnesium intrusion brines, the critical pitting ratio is below 1.5 for both CHLW and SFPWR packages at 10,000 years. Therefore, conditions that cause pitting should be identified and avoided if possible for intrusion brines.

It is conceivable that corrosion could be limited by diffusion of brine or intermediate species through a thick, adherent iron oxide layer or anhydrite precipitate. This analysis included no consideration of any limitation of that type.

6.4.2.3.4 Release Rate From the Engineered Barrier Subsystem. For the purpose of this preliminary performance assessment, the engineered barrier subsystem boundary is the outside surface of each container of each waste package. Nuclide releases from the engineered barrier subsystem to the geologic subsystem are assumed to commence at the time of failure of the container and are assumed to be limited only by the quantity of each nuclide that would dissolve into the quantity of brine available (ignoring the consumption of brine by chemical reaction with the container). Synergistic effects which result in lower solubilities, such as saturation with iron, presence of carbon in carbides (rather than assume 100 percent carbonate), etc., are ignored. These and other effects will be examined both experimentally and theoretically (using a geochemical equilibrium code modified for high ionic strength) during site characterization.

Brine accumulations around the packages with and without consumption of brine by corrosion are shown in Figure 6-18 for both packages in Richton Dome. This shows that all of the brine reaching the package is promptly used up by chemical reaction with the iron in the

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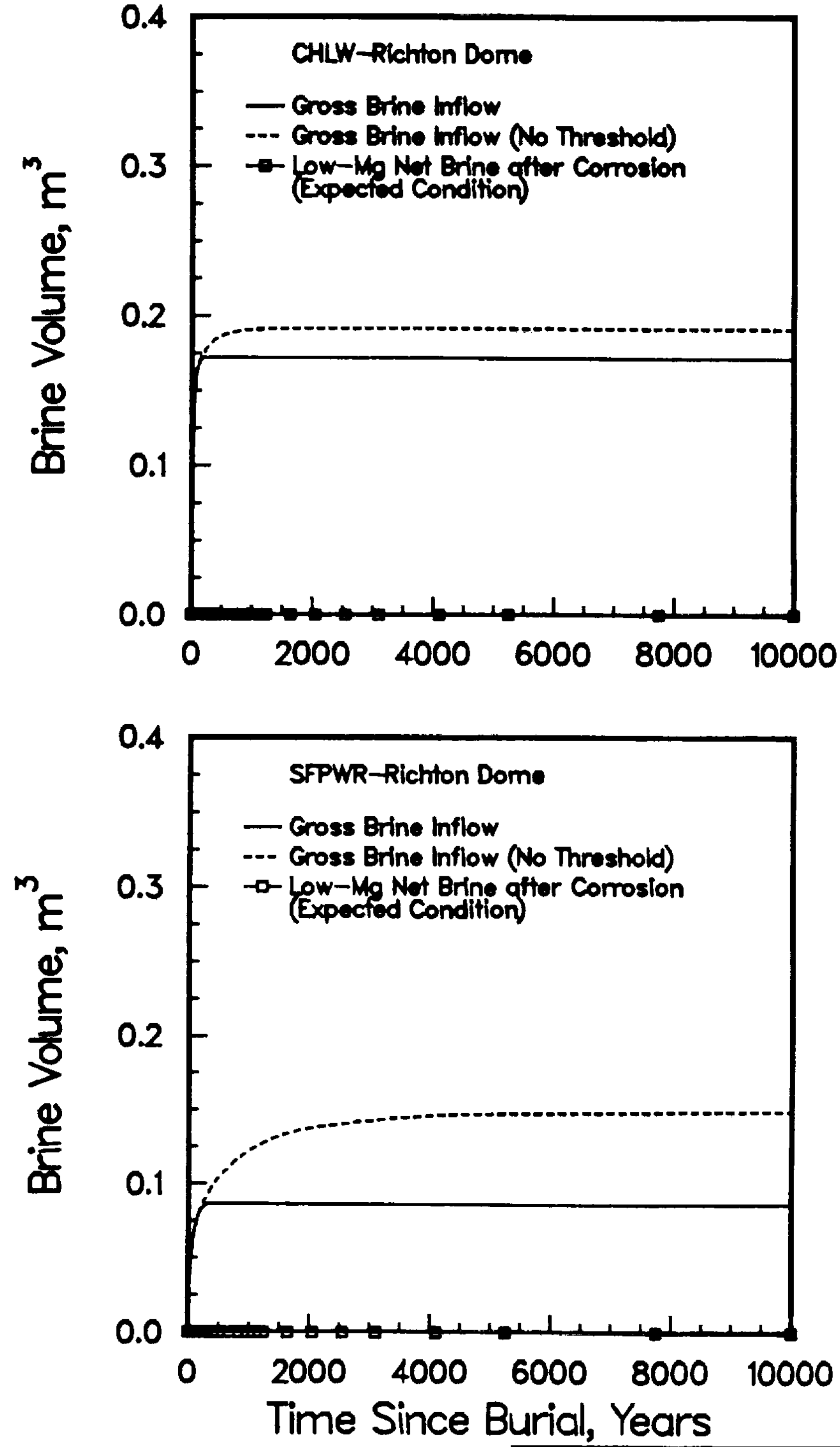
*We define pitting ratio here as the ratio of the uniformly corroded thickness plus the depth of of the pit or crack to the uniformly corroded thickness.



Source: Jansen, 1985

Net Accumulated Brine During Corrosion of the Waste Package

Figure 6-18

container. The net brine left after chemical reaction with the steel container will be much less than the gross accumulated brine volume. This will reduce the potential for leaching of radionuclides from the waste form; however, the gross volume of brine is used to compute an upper limit to the release of radionuclides across the package surface. This has been done using the solubility limits given in Table 6-32. These are taken from the NAS Waste Isolation Systems Panel (WISP) report (Pigford, 1983) with addition of measured values for saturated radium concentrations in brines in the field (Langmuir, 1983), and nominal values for highly soluble cesium chloride and sodium iodide salts in water and for carbon in carbonate saturated ground water (Card and Jansen, 1975). Several data sets exist from which solubility information may be drawn (Fournier and Rowe, 1977; Muller et al., 1981, NUREG/CR-1996; Rai et al., 1981; Rai et al., 1983; Rai and Ryan, 1982; Rai and Ryan, 1984, PNL-SA-11489; Ryan and Rai, 1983; Van Luik and Jurinak, 1979); none of these is based on site-specific conditions. For the purpose of this preliminary assessment, the information from Pigford (1983) has been selected as generally representative of expected solubility values.

It should be noted that there are probably inadequacies in any currently available data set. The effects of high ionic strength solutions, temperature, and pressure on radionuclide solubility are not completely understood. Also the thermodynamic data base for various radionuclide solution species is subject to uncertainties and estimations and, therefore, is not adequate for definitive calculations. One computer code, EQ3/EQ6, is currently being modified for use on repository conditions (INTERA, 1983, ONWI-472). The radionuclide release calculations in Sections 6.4.2.3 and 6.4.2.4 will continually be updated with state-of-the-art codes as new data and computational methods become available. Solubilities of most radionuclides in brine are a strong function of Eh and pH, neither of which is expected to be significantly affected by the near-field radiation field of only about 20 rads per hour (Sections 6.3.1.2.2 and 6.3.1.2.3). Future research will further document the effects of radiolysis on oxidation-reduction potential at repository-relevant dose rates. Solubilities expected in anoxic brines would be lower than the WISP (Pigford, 1983) estimates.

The preliminary results for CHLW and SFPWR packages are compared in Tables 6-32 and 6-33 with the EPA 40 CFR Part 191 individual nuclide limits at the repository site boundary prorated to each package. The sum of these release ratios at the accessible environment must not exceed unity. For all elements except cesium and iodine, the expected gross volume of brine saturated with the element limits the radionuclide discharges to small fractions of the EPA limit. Those fractions would be even lower if credit were taken for the fact that not all of the packages in a repository will fail simultaneously.

Except for cesium-137 the volume of saturated brine to dissolve enough radioactivity to reach the individual nuclide EPA limit ranges from 4.8 cubic meters for strontium-90 in the SFPWR package to 820 billion cubic meters for uranium-233. These brine volumes are unattainable unless the brine migration model (Section 6.4.2.3.2) grossly underestimates available brine.

The rate of supply of brine to the package surface limits the rate of release of radionuclides from the package under expected conditions. If it is conservatively assumed that the gross brine flow rate without a thermal gradient threshold becomes saturated in the chemical elements contained in the waste as it reaches the package, an upper bound on any radionuclide release rate can be computed by multiplying the brine inflow rate by the solubility of the chemical element. Then the release rate from the package can be compared with the 10 CFR Part 60 (NRC, 1983, Sec. 60.113, p. 60-12) release rate limits for the engineered subsystem. If the package releases were to satisfy the 10 CFR Part 60 limits and the EPA standards, no requirements for retardation or prevention of release need be placed on other repository components.

The results of such calculations for the 10 CFR Part 60 limits are presented in Table 6-34 for CHLW and in Table 6-35 for the SFPWR package at the NRC-mandated minimum package lifetime of 300 years and at other times of interest. Half-lives of the nuclides are taken from the Chart of the Nuclides (General Electric, 1984). Including both packages, the expected maximum release rates at 300 years, even with the omission of many retarding factors, are below the NRC limit of 10^{-5} per year of the nuclide inventory at 1,000 years for all

Table 6-32. Richton Dome CHLW Package. Comparison of Solubility and Accumulated Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment

The volume of brine is 0.17 m^3 made available by brine thermal migration with a threshold thermal gradient of 0.125 C/cm.

Element	Solubility,[a] grams/m^3	Package Inventory,[b] grams	Dissolved in Brine, grams	Nuclide	EPA Limit,[c] Curies per 1,000 MTIHM[e]	Ratio of Radioactivity[b] in Brine to EPA Limit	Total Volume of Saturated Brine to Reach EPA Limit, m^3
Carbon	0.06	1,608[d]	0.01	C-14	100	0.94E-4	1,800
Selenium	0.001	539	1.7E-4	Se-79	1,000	0.13E-6	1.3E+6
Strontium	0.8	3,375	0.14	Sr-90	100	0.018	9.4
Technetium	0.001	7,368	1.7E-4	Tc-99	10,000	0.30E-7	5.7E+6
Tin	0.0001	915	1.7E-5	Sn-126	1,000	0.14E-7	1.2E+7
Iodine	600,000.	2,238[d]	2,238	I-129	100	0.31	Not saturated
Cesium	600,000.	13,664	13,664	Cs-135	1,000	0.34	Not saturated
				Cs-137	1,000	80 (meets limit by decay at 490 years)	
Thorium	0.001	0.09	1.7E-4	Th-232	10	0.31E-10	5.4E+9
Uranium	0.001	46,153	1.7E-4	U-233	100	0.16E-10	1.0E+10
				U-235	100	0.32E-11	5.3E+10
				U-236	100	0.49E-10	3.5E+9
				U-238	100	0.58E-10	2.9E+9
Neptunium	0.001	5,940	1.7E-4	Np-237	100	0.12E-6	1.4E+6
Plutonium	0.001	540	1.7E-4	Pu-238	100	0.10E-4	1.7E+4
				Pu-239	100	0.54E-5	3.2E+4
				Pu-240	100	0.19E-4	9,100
				Pu-241	1,000	0.48E-7	3.6E+6
				Pu-242	100	0.28E-07	6.2E+6
Americium	0.0001	3,731	1.7E-5	Am-241	100	0.48E-04	3,600
				Am-243	100	0.73E-6	2.3E+5
Curium	0.001	8.6	1.7E-4	Cm-244	100	0.26E-5	6.6E+4

Table 6-32. Richton Dome CHLW Package. Comparison of Solubility and Accumulated Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment (Page 2 of 2)

	10,000 year Inventory, grams	Nuclide	Specific Activity, Ci/g Time, years					Ratio of Radioactivity in Brine to EPA Limit Time, years				
			200	300	500	1,000	10,000	200	300	500	1,000	10,000
Carbon	1,607	C-14	9.0E-3	8.9E-3	8.7E-3	8.2E-3	2.8E-3	9.5E-5	9.4E-5	9.2E-5	8.6E-5	2.9E-5
Selenium	533	Se-79	7.2E-3	7.2E-3	7.2E-3	7.2E-3	6.6E-3	1.3E-7	1.3E-7	1.3E-7	1.3E-7	1.2E-7
Strontium	3,351	Sr-90	1.4	0.13	1.1E-3	7.5E-9	0.0	0.20	0.018	1.6E-4	1.1E-9	0.0
Technetium	7,139	Tc-99	0.017	0.017	0.017	0.017	0.017	3.0E-8	3.0E-8	3.0E-8	3.0E-8	3.0E-8
Tin	897	Sn-126	8.1E-3	8.1E-3	8.1E-3	8.1E-3	7.7E-3	1.4E-8	1.4E-8	1.4E-8	1.4E-8	1.4E-8
Iodine	2,237	I-129	1.3E-4	1.3E-4	1.3E-4	1.3E-4	1.3E-4	0.31	0.31	0.31	0.31	0.31
Cesium	13,597	Cs-135	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	0.34	0.34	0.34	0.34	0.34
		Cs-137	0.57	0.056	5.6E-4	5.3E-9	0.0	800	80	0.78	7.5E-6	0.0
Thorium	1.1	Th-232	1.8E-8	1.8E-8	1.7E-8	1.5E-8	9.5E-9	3.2E-11	3.1E-11	3.0E-11	2.7E-11	1.7E-11
Uranium	46,465	U-233	6.6E-8	9.4E-8	1.9E-7	4.4E-7	5.6E-6	1.2E-11	1.7E-11	3.4E-11	7.8E-11	9.9E-10
		U-235	1.8E-8	1.8E-8	1.8E-8	1.9E-8	2.4E-8	3.2E-12	3.2E-12	3.2E-12	3.3E-12	4.3E-12
		U-236	2.7E-7	2.8E-7	2.8E-7	3.0E-7	5.0E-7	4.8E-11	4.9E-11	5.0E-11	5.3E-11	8.7E-11
		U-238	3.3E-7	3.3E-7	3.3E-7	3.3E-7	3.3E-7	5.8E-11	5.8E-11	5.8E-11	5.8E-11	5.8E-11
Neptunium	8,905	Np-237	7.1E-4	7.1E-4	7.1E-4	7.1E-4	7.1E-4	1.2E-7	1.2E-7	1.2E-7	1.2E-7	1.2E-7
Plutonium	703	Pu-238	0.088	0.056	0.023	2.3E-3	2.8E-21	1.6E-5	1.0E-5	4.1E-6	4.1E-7	5.0E-25
		Pu-239	0.030	0.030	0.032	0.034	0.052	5.3E-6	5.4E-6	5.6E-6	6.0E-6	9.2E-6
		Pu-240	0.11	0.11	0.10	0.094	0.029	1.9E-5	1.9E-5	1.8E-5	1.7E-5	5.1E-6
		Pu-241	2.9E-3	2.7E-3	2.4E-3	2.2E-3	8.5E-4	5.1E-8	4.8E-8	4.2E-8	3.9E-8	1.5E-8
		Pu-242	1.6E-4	1.6E-4	1.6E-4	1.5E-4	1.2E-4	2.8E-8	2.8E-8	2.8E-8	2.7E-8	2.2E-8
Americium	312	Am-241	2.8	2.7	2.5	2.0	1.9E-3	4.9E-5	4.8E-5	4.5E-5	3.4E-5	3.4E-8
		Am-243	0.037	0.041	0.052	0.086	0.20	6.5E-7	7.3E-7	9.2E-7	1.5E-6	3.5E-6
Curium	3.7	Cm-244	0.66	0.015	7.1E-6	2.9E-13	5.4E-13	1.2E-4	2.6E-6	1.3E-9	5.0E-17	9.4E-17

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable to these preliminary analyses. More specifically, carbon solubility data could be controlled by kinetics and not by equilibrium conditions.
(b) Value at 300 years.
(c) EPA, 1985.
(d) This element is not in the CHLW package. It would be separated in the fuel reprocessing plant and stored separately.
(e) MTIHM = metric tons of initial heavy metal.

Table 6-33. Richton Dome SFPWR Package. Comparison of Solubility and Maximum Brine Volume Limited Accumulated Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment

The volume of brine is 0.082 m^3 made available by brine thermal migration with a threshold thermal gradient.

Element	Solubility,[a] grams/m^3	Package Inventory,[b] grams	Dissolved in Brine, grams	Nuclide	EPA Limit,[c] Curies per 1,000 MTIHM	Ratio of Radioactivity[b] in Brine to EPA Limit	Total Volume of Saturated Brine to Reach EPA Limit, m^3
Carbon	0.06	833	0.0049	C-14	100	0.87E-4	940
Selenium	0.001	279	8.2E-5	Se-79	1,000	0.12E-6	6.9E+5
Strontium	0.8	1,747	0.066	Sr-90	100	0.017	4.8
Technetium	0.001	3,812	8.2E-5	Tc-99	10,000	0.28E-7	2.9E+6
Tin	0.0001	19,216	8.2E-6	Sn-126	1,000	0.33E-9	2.5E+8
Iodine	600,000.	1,157	1,157.	I-129	100	0.31	Not saturated
Cesium	600,000.	7,069	7,069.	Cs-135	1,000	0.34	Not saturated
				Cs-137	1,000	80. (meets limit by decay at 490 years)	
Thorium	0.001	1.19	8.2E-5	Th-232	10	0.25E-10	3.3E+9
Uranium	0.001	4,774,600	8.2E-5	U-233	100	0.10E-12	8.2E+11
				U-235	100	0.30E-11	2.7E+10
				U-236	100	0.45E-10	1.8E+9
				U-238	100	0.54E-10	1.5E+9
Neptunium	0.001	4,276	8.2E-5	Np-237	100	0.12E-6	7.1E+5
Plutonium	0.001	38,380	8.2E-5	Pu-238	100	0.46E-5	1.8E+4
				Pu-239	100	0.66E-5	1.2E+4
				Pu-240	100	0.11E-4	7,500
				Pu-241	1,000	0.33E-8	2.5E+7
				Pu-242	100	0.36E-7	2.3E+6
Americium	0.0001	4,301	8.2E-6	Am-241	100	0.51E-4	1,600
				Am-243	100	0.31E-6	2.7E+5
Curium	0.001	4.5	8.2E-5	Cm-244	100	0.24E-5	3.4E+4

Table 6-33. Richton Dome SFPWR Package. Comparison of Solubility and Maximum Brine Volume Limited Accumulated Release at a Failed Waste Package Boundary with EPA Discharge Limits to the Accessible Environment (Page 2 of 2)

	10,000-year Inventory, grams	Nuclide	Time, years					Time, Years				
			200	300	500	1,000	10,000	200	300	500	1,000	10,000
			Specific Activity, Ci/g					Ratio of Radioactivity in Brine to EPA Limit				
Carbon	832	C-14	9.0E-3	8.9E-3	8.7E-3	8.2E-3	2.7E-3	8.9E-5	8.7E-5	8.5E-5	8.0E-5	2.7E-5
Selenium	276	Se-79	7.2E-3	7.2E-3	7.2E-3	7.2E-3	6.6E-3	1.2E-7	1.2E-7	1.2E-7	1.2E-7	1.1E-7
Strontium	1,736	Sr-90	1.4	0.13	1.1E-3	7.5E-9	0	0.18	0.017	1.5E-4	9.9E-9	0.0
Technetium	3,694	Tc-99	0.017	0.017	0.017	0.017	0.017	2.8E-8	2.8E-8	2.8E-8	2.8E-8	2.8E-8
Tin	19,206	Sn-126	2.0E-4	2.0E-4	2.0E-4	2.0E-4	1.9E-4	3.3E-10	3.3E-10	3.3E-10	3.3E-10	3.3E-10
Iodine	1,157	I-129	1.3E-4	1.3E-4	1.3E-4	1.3E-4	1.3E-4	0.31	0.31	0.31	0.31	0.31
Cesium	7,031	Cs-135	2.4E-4	2.4E-4	2.4E-4	2.4E-4	2.4E-4	0.33	0.33	0.34	0.34	0.34
		Cs-137	0.56	0.056	5.6E-4	5.3E-9	0	800	0.79	0.78	7.5E-6	0.0
Thorium	50	Th-232	1.5E-8	1.5E-8	1.4E-8	1.3E-8	1.6E-8	2.5E-11	2.5E-11	2.5E-11	2.5E-11	2.5E-11
Uranium	4,787,910	U-233	4.1E-10	6.1E-10	1.3E-10	3.4E-9	5.0E-8	6.8E-14	1.0E-13	2.2E-13	5.5E-13	5.2E-12
		U-235	1.8E-8	1.8E-8	1.8E-8	1.9E-8	2.1E-8	3.0E-12	3.0E-12	3.0E-12	3.1E-12	3.5E-12
		U-236	2.7E-7	2.8E-7	2.8E-7	2.8E-7	3.7E-7	4.4E-11	4.5E-11	4.5E-11	4.6E-11	6.0E-11
		U-238	3.3E-7	3.3E-7	3.3E-7	3.3E-7	3.3E-7	5.5E-11	5.5E-11	5.5E-11	5.5E-11	5.4E-11
Neptunium	8,244	Np-237	7.1E-4	7.1E-4	7.1E-4	7.1E-4	7.1E-4	1.2E-7	1.2E-7	1.2E-7	1.2E-7	1.2E-7
Plutonium	25,200	Pu-238	0.061	0.028	0.0059	1.3E-4	4.1E-23	1.0E-5	4.6E-5	9.7E-7	2.2E-8	6.8E-27
		Pu-239	0.040	0.040	0.041	0.041	0.047	6.6E-6	6.7E-6	6.7E-6	6.7E-6	7.7E-6
		Pu-240	0.067	0.066	0.066	0.064	0.036	1.1E-5	1.1E-5	1.1E-5	1.1E-5	5.9E-6
		Pu-241	6.7E-4	2.0E-4	1.8E-5	1.7E-5	1.2E-5	1.1E-8	3.3E-9	2.9E-10	2.8E-10	2.0E-10
		Pu-242	2.2E-4	2.2E-4	2.2E-4	2.3E-4	3.3E-4	3.6E-8	3.6E-8	3.7E-8	3.7E-8	5.4E-8
Americium	162	Am-241	3.2	3.1	3.0	2.6	1.9E-3	5.2E-5	5.1E-5	4.9E-5	4.4E-5	3.2E-8
		Am-243	0.016	0.019	0.024	0.046	0.20	2.7E-7	3.1E-7	4.0E-7	7.5E-7	3.3E-6
Curium	1.9	Cm-244	0.66	0.015	7.1E-6	2.9E-13	5.4E-13	1.1E-4	2.4E06	1.2E-5	4.6E-14	8.8E-17

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable for these preliminary analyses. More specifically, carbon solubility could be controlled by kinetics and not by equilibrium conditions.

(b) Value at 300 years.

(c) EPA, 1985.

Table 6-34. Richton Dome CHLW Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60

The gross brine inflow rate is 3.7 E-5 m^3 per year at 300 years after burial.

Element	Solubility[a], grams/m^3	300-yr Package Inventory,[b] grams	Quantity Required to Saturate Incoming Brines, grams/yr	Nuclide	Activity From Package to Brine, Curies/yr	Ratio to 1,000-yr Nuclide Activity/ (1E-5 per yr)	Ratio to 1,000-yr Total Activity/ (1E-8 per yr)
Carbon	0.06	1,608[c]	2.2E-6	C-14	2.0E-8	1.5E-4	(d)
Selenium	0.001	539	3.7E-8	Se-79	2.7E-10	6.9E-6	(d)
Strontium	0.8	3,375	3.0E-5	Sr-90	3.8E-6	15,000.	0.099
Technetium	0.001	7,368	3.7E-8	Tc-99	6.3E-10	5.0E-7	(d)
Tin	0.0001	915	3.7E-9	Sn-126	3.0E-11	4.1E-7	(d)
Iodine	600,000.	2,238[c]	22.	I-129	0.0030	990.	77
Cesium	600,000.	13,664	22.	Cs-135	0.0053	160.	140
				Cs-137	1.2	1.7E+9	32,000
Thorium	0.001	0.090	3.7E-8	Th-232	6.6E-16	0.032	(d)
Uranium	0.001	46,153.	3.7E-8	U-233	3.5E-15	1.7E-8	(d)
				U-235	6.8E-16	7.9E-8	(d)
				U-236	1.0E-14	7.3E-8	(d)
				U-238	1.2E-14	8.0E-8	(d)
Neptunium	0.001	5,940.	3.7E-8	Np-237	2.6E-11	4.6E-7	(d)
Plutonium	0.001	540.	3.7E-8	Pu-238	2.1E-9	1.6E-4	(d)
				Pu-239	1.1E-9	5.9E-6	(d)
				Pu-240	3.9E-9	7.4E-6	(d)
				Pu-241	1.0E-10	8.1E-6	(d)
				Pu-242	5.8E-12	6.7E-6	(d)
Americium	0.0001	3,730.	3.7E-9	Am-241	1.0E-8	3.0E-7	(d)
				Am-243	1.5E-10	1.1E-7	(d)
Curium	0.001	8.6	3.7E-8	Cm-244	5.4E-10	1.9E+8	1.4E-5

Table 6-34. Richton Dome CHLW Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60 (Page 2 of 2)

Element	Inventory/ Package, grams at 1,000 years	Nuclide	Ratio of Radioactivity in Brine to NRC Limit Using 1,000-yr Inventory, Fraction 1,000-yr NRC Limit of 1E-5 per year per Nuclide Inv.				of 1E-8 per year per Total Activity			
			200 yrs.	300 yrs.	500 yrs.	1,000 yrs.	200 yrs.	300 yrs.	500 yrs.	1,000 yrs.
Carbon	1,607	C-14	2.5E-4	1.5E-4	5.5E-5	8.4E-6	8.4E-4	5.1E-4	1 9E-4	2.9E-5
Selenium	538	Se-79	1.1E-5	6.9E-6	2.6E-6	4.2E-7	1.1E-5	6.9E-6	2.6E-6	4.2E-7
Strontium	3,351	Sr-90	2.6E+5	1.5E+4	49.	5.4E-5	1.7	0.099	3.2E-4	3.5E-10
Technetium	7,351	TC-99	8.2E-7	5.0E-7	1.9E-7	3.1E-8	2.6E-5	1.6E-5	6.1E-6	9.9E-6
Tin	913	Sn-126	6.6E-7	4.0E-7	1.5E-7	7.5E-8	1.4E-6	7.7E-7	2.9E-7	4.7E-8
Iodine	2,238	I-129	1,600.	990.	370.	60.	130.	77.	29.	4.7
Cesium	13,607	Cs-135	260.	160.	61.	9.9	220	140.	52.	8.4
		Cs-137	2.8E+10	1.7E+9	6.4E+6	9.9	5.3E+5	3.2E+4	120.	1.9E-4
Thorium	0.136	Th-232	0.053	0.032	0.011	1.7E-3	2.9E-11	1.7E-11	6.1E-12	8.9E-13
Uranium	46,175	U-233	1.9E-8	1.7E-8	1.3E-8	4.9E-9	1.0E-10	9.0E-11	6.9E-11	2.6E-11
		U-235	1.3E-7	7.9E-8	3.0E-8	4.9E-9	2.9E-11	1.9E-11	6.6E-12	1.2E-12
		U-236	1.2E-7	7.3E-8	2.8E-8	4.9E-9	4.3E-10	2.7E-10	1.1E-10	1.9E-11
		U-238	1.3E-7	8.0E-8	3.0E-8	4.9E-9	5.2E-10	3.2E-10	1.3E-10	2.1E-11
Neptunium	7,987	Np-237	7.5E-7	4.6E-7	1.7E-7	7.8E-8	2E-6	6.7E-7	2.5E-7	4.1E-8
Plutonium	564	Pu-238	4.0E-4	1.6E-4	2.4E-5	4.0E-7	1.5E-4	5.4E-5	8.3E-6	1.5E-7
		Pu-239	9.4E-6	5.9E-6	2.3E-6	4.0E-7	4.7E-5	2.9E-5	1.2E-5	2.2E-6
		Pu-240	1.2E-5	7.3E-6	2.7E-6	4.0E-7	1.8 -4	1.1E-4	3.7E-5	5.5E-6
		Pu-241	1.4E-5	8.1E-6	2.6E-6	4.0E-7	4.5E-6	2.6E-6	8.5E-7	1.4E-7
		Pu-242	1.1E-5	6.7E-6	2.5E-6	4.0E-7	2.4E-7	1.6E-7	5.6E-8	9.0E-9
Americium	1,683	Am-241	5.1E-7	3.0E-7	1.1E-7	1.3E-8	4.4E-4	2.8E-4	9.1E-5	1.3E-5
		Am-243	1.5E-7	1.1E-7	5.0E-8	1.3E-8	5.8E-6	4.0E-6	1.9E-6	5.0E-7
Curium	8.0	Cm-244	1.4E+10	1.9E+8	3.4E+4	2.8E-5	0.001	1.4E-5	2.6E-9	2.3E-18
Brine Rate with Zero Threshold Gradient, (m^3/yr)			6.0E-5	3.7E-5	1.4E-5	2.3E-6	6.0E-5	3.7E-5	1.4E-5	2.3E-6

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable for these preliminary analyses. More specifically, carbon solubility data could be controlled by kinetics and not by equilibrium conditions.

(b) The thorium, neptunium, and plutonium grow larger with time, so that at 10,000 years, these inventories are 1.1, 8,905, and 703 grams per package, respectively.

(c) This element is not in the CHLW package; it would be separated in the fuel reprocessing plant and stored separate.

(d) This value is not shown unless the primary (10^{-5}) standard is not met, indicated by a value greater than one in the preceding column.

Table 6-35. Richton Dome SFPWR Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60

The gross brine inflow rate is 7.3E-5 m^3 per year at 300 years after burial.

Element	Solubility,[(a)] grams/m^3	300-yr Package Inventory,[(b)] grams	Quantity Required to Saturate Incoming Brines, grams/yr	Nuclide	Activity From Package to Brine, Curies/yr	Ratio to 1,000-yr Nuclide Activity/ (1E-5 per yr)	Ratio to 1,000-yr Total Activity/ (1E-8 per yr)
Carbon	0.06	833	4.4E-6	C-14	3.9E-8	5.8E-4	(c)
Selenium	0.001	279	7.3E-8	Se-79	5.3E-10	2.7E-5	(c)
Strontium	0.8	1,747	5.9E-5	Sr-90	7.6E-6	58,000.	0.088
Technetium	0.001	3,812	7.3E-8	Tc-99	1.2E-9	1.9E-6	(c)
Tin	0.0001	19,216	7.3E-9	Sn-126	1.5E-12	3.8E-8	(c)
Iodine	600,000.	1,157	44.	I-129	0.0059	3,800.	70.
Cesium	600,000.	7,069	44.	Cs-135	0.010	620.	120.
				Cs-137	2.5	6.6E+9	29,000.
Thorium	0.001	1.19	7.3E-8	Th-232	1.1E-15	1.7E-3	(c)
Uranium	0.001	4,774,600	7.3E-8	U-233	4.5E-17	2.8E-10	(c)
				U-235	1.4E-15	1.5E-9	(c)
				U-236	2.0E-14	1.5E-9	(c)
				U-238	2.4E-14	1.5E-9	(c)
Neptunium	0.001	4,276	7.3E-8	Np-237	5.2E-11	1.0E-6	(c)
Plutonium	0.001	38,380	7.3E-8	Pu-238	2.1E-9	4.2E-5	(c)
				Pu-239	3.0E-9	2.0E-7	(c)
				Pu-240	4.9E-9	2.1E-7	(c)
				Pu-241	1.5E-11	2.3E-6	(c)
				Pu-242	1.6E-11	1.9E-7	(c)
Americium	0.0001	4,301	7.3E-9	Am-241	2.3E-8	5.2E-7	(c)
				Am-243	1.4E-10	1.8E-7	(c)
Curium	0.001	4.5	7.3E-8	Cm-244	1.1E-9	7.2E+8	1.3E-5

Table 6-35. Richton Dome SFPWR Package. Comparison of Package Release Rates to Saturate Incoming Brine at the Waste Package Boundary with NRC Engineered System Release Rate Limits in 10 CFR Part 60
(Page 2 of 2)

Element	Inventory/ Package, grams at 1,000 years	Nuclide	Ratio of Radioactivity in Brine to NRC Limit Using 1,000-Year Inventory, Fraction of 1E-5 per year per Nuclide Inv.				Ratio of Radioactivity in Brine to NRC Limit Using 1,000-Year Inventory, Fraction of 1E-8 per year per Total Activity			
			200 yrs.	300 yrs.	500 yrs.	1,000 yrs.	200 yrs.	300 yrs.	500 yrs.	1,000 yrs.
Carbon	833	C-14	7.3E-4	5.8E-4	3.6E-4	1.8E-4	5.9E-4	4.7E-4	2.9E-4	1.5E-4
Selenium	278	Se-79	3.3E-5	2.7E-5	1.7E-5	9.0E-6	7.8E-6	6.4E-6	4.1E-6	2.2E-6
Strontium	1,736	Sr-90	7.8E-5	5.8E+4	320.	1.2E-3	1.2	0.088	5.0E-4	1.8E-9
Technetium	3,804	Tc-99	2.4E-6	1.9E-6	1.2E-6	6.6E-7	1.9E-5	1.5E-5	9.5E-6	5.1E-6
Tin	19,216	Sn-126	4.8E-8	3.8E-8	2.5E-8	1.3E-8	2.2E-8	1.8E-8	1.1E-8	6.0E-9
Iodine	1,157	I-129	4.8E+3	3.8E+3	2.4E+3	1.3E+3	870.	71.	46.	24.
Cesium	7,036	Cs-135	780.	620.	400.	210.	150.	120.	80.	43.
		Cs-137	8.3E+10	6.6E+9	4.2E+7	210.	3.7E+5	3.0E+4	180.	9.6E-4
Thorium	4.9	Th-232	2.2E-3	1.7E-3	1.0E-3	5.2E-4	1.7E-11	1.3E-11	7.7E-12	4.0E-12
Uranium	4,775,930	U-233	2.4E-10	2.8E-10	3.9E-10	5.4E-10	4.4E-13	5.2E-13	7.3E-13	9.9E-13
		U-235	1.9E-9	1.5E-9	9.8E-10	5.3E-10	2.0E-11	1.6E-11	1.0E-11	5.5E-12
		U-236	1.8E-9	1.5E-9	9.6E-10	5.3E-10	2.9E-10	2.3E-10	1.5E-10	8.3E-11
		U-238	1.9E-9	1.5E-12	9.9E-10	5.3E-10	3.6E-10	2.9E-10	1.8E-10	9.7E-11
Neptunium	7,021	Np-237	1.3E-6	1.0E-6	6.7E-7	3.6E-7	7.6E-7	6.1E-7	3.9E-7	2.1E-7
Plutonium	37,011	Pu-238	1.1E-4	4.2E-5	5.7E-6	6.8E-8	6.5E-5	2.4E-5	3.2E-6	3.9E-8
		Pu-239	2.4E-7	2.0E-7	1.3E-7	6.8E-8	4.3E-5	3.5E-5	2.2E-5	1.2E-5
		Pu-240	2.6E-7	2.1E-7	1.3E-7	6.8E-8	7.2E-5	5.7E-5	3.6E-5	1.9E-5
		Pu-241	9.7E-6	2.3E-6	1.3E-7	6.8E-8	7.2E-7	1.7E-7	9.7E-9	5.2E-9
		Pu-242	2.4E-7	1.9E-7	1.2E-7	6.8E-8	2.3E-7	1.9E-7	1.2E-7	6.7E-8
Americium	1,642	Am-241	6.7E-7	5.3E-7	3.3E-7	1.5E-7	3.4E-4	2.7E-4	1.7E-4	7.8E-5
		Am-243	2.0E-7	1.8E-7	1.5E-7	1.5E-7	1.8E-6	1.6E-6	1.4E-6	1.4E-6
Curium	4.1	Cm-244	4.1E+10	7.2E+8	2.2E+5	6.1E-4	7.3E-4	1.3E-5	4.0E-9	1.1E-17
Brine Rate with Zero Threshold Thermal Gradient (m^3/yr)			9.2E-5	7.3E-5	4.7E-5	2.5E-5	9.2E-5	7.3E-5	4.7E-5	2.5E-5

(a) Various other solubility data exist, some with higher and some with lower values for various nuclides. These other data may be no more or no less applicable for these preliminary analyses. More specifically, carbon solubility data could be controlled by kinetics and not by equilibrium conditions.

(b) The radium, thorium, and neptunium grow larger with time, so that at 10,000 years these inventories are 0.67, 49.5, and 8,243 grams per package, respectively.

(c) This value is not shown unless the primary (10^{-5}) standard is not met, indicated by a value greater than one in the preceding column.

radionuclides except Sr-90, I-129, Cs-135, Cs-137, and Cm-244. An alternate limit given in 10 CFR Part 60 may be applied to these nuclides. This limit, 0.1 percent of 10^{-5}, i.e., 10^{-8} of the total 1,000-year activity in the package, is generally met by short-lived nuclides or those present originally in extremely small quantities. In these calculations, Sr-90 and Cm-244 meet the alternate limit. Thus, I-129, Cs-135, and Cs-137 in both packages need constraints other than just a 300-year package to meet the 10 CFR Part 60 limits. For example, the alternate limit could be met for Cs-137 with additional decay beyond 300 years of about 450 and 460 years for SFPWR and CHLW, respectively. Half-lives of I-129 (15.9 million years) and Cs-135 (2.3 million years) are too long for demonstrable package lives to contain. However, the total inventory of Cs-135 and I-129 could be released into the accessible environment without violating 40 CFR Part 191 EPA standards.

If the waste form leach fraction is less than about 0.007 per year, Cs-135 and I-129 would meet the alternate limit even with a 300-year package for either waste form. An interim performance specification for waste forms of 10^{-4} fractional release per year has been published (ONWI, 1983, ONWI-462, p. 11). If this specification were used with Cs-137, the package would only have to last 50 to 60 more years than the minimum requirement of 300 for it to meet the 10 CFR Part 60 engineered subsystem alternate release limit.

The results described in this section assume package failure. The expected condition does not indicate package failure; thus these calculations demonstrate redundancy in that even if the package fails, limited solubility and quantities of brine limit the radionuclide release from the engineered subsystem. Other factors, as discussed but not specifically included in this preliminary analysis, also limit radionuclide release.

Summary of Performance of Engineered Barriers. There will be no radionuclide release under expected conditions from either CHLW or SFPWR packages because the package will not fail under expected corrosion conditions. If the package should fail, e.g., from human intrusion, the solubilities of the radionuclide elements in the expected total volume of thermally migrated brine (even without the expected volume reduction due to chemical reaction with overpack steel) will limit the radionuclide release from the package to within individual nuclide EPA limits prorated per package, except for Cs-137. It is recognized that the site limit consists of the sum of ratios for all nuclides. However, examination of individual ratios provides a perspective on actions that would help to meet these standards. Cs-137 will decay radioactively to meet its limit at only 490 years (Tables 6-32 and 6-33), even though 750 or 760 years are required for meeting NRC limits. Since either of these durations is much less time than the travel time to the accessible environment boundary along any pathway, Cs-137 is of little significance in meeting EPA criteria. Furthermore, even brine volume saturation-limited releases are probably not physically attainable because of the omission in the calculations of many retarding factors.

The 10 CFR Part 60 standards are met if the expected conditions prevail (i.e., that the waste package remains intact for a very long time). Even if a package fails, the brine would have been consumed up to that time and other factors retard releases; thus waste form releases would be limited. These bounding calculations, assuming no thermal gradient threshold for brine migration, no brine consumed by chemical reaction after package failure, and package failure, indicate that Cs-137 is the limiting nuclide and, ignoring other factors other than a waste form specification of 10^{-4}, that the package would have to last 350 to 360 years to meet 10 CFR Part 60.

6.4.2.3.5 Geologic Subsystem Performance. The performance of the geologic subsystem for a salt repository is reflected primarily by considerations of (1) the migration of brine toward the heat sources provided by the waste packages, (2) the possible mobility of brine with dissolved radionuclides by diffusing away from waste packages after package failure, and (3) the flow of ground water with dissolved radionuclides toward the accessible environment if radioactivity has been encountered by the ground water for any reason. The presence of a disturbed zone in which accelerated flow might occur is hypothesized by 10 CFR Part 60. The extent of the disturbed zone will be estimated and, for the purposes of these analyses, any travel time required to transit the disturbed zone will not be included. In addition, inadequate or faulty shaft seals might affect radionuclide transport. Seal performance will be discussed.

Brine migration toward heat sources was described in Section 6.4.2.3.2; brine movement away from the waste by a diffusion process and the possibility of ground-water flow in intact salt and through or around seals will be described in this section. In addition, ground-water flow in nearby aquifers will be described in this section.

Estimation of the Extent of the Disturbed Zone. The disturbed zone is defined as, "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 the geologic repository" (10 CFR 960.2, Definitions). The definition is consistent with that given in 10 CFR Part 60; however, in order to be useful, the dimensions of the disturbed zone must be quantified. An estimate of these dimensions is given in Appendix 6-A.

Several processes and phenomena that could affect the rock surrounding the repository are discussed in Appendix 6-A. The estimates for the size of the disturbed zone are listed in Table 6-36. The maximum size of the disturbed zone is estimated to be about 15 meters (49 feet). This estimate may be revised when site-specific data at the repository horizon become available.

Brine Mobility Away From Waste. McNulty et al. (1985) give the equations that govern the transport of brine away from the waste package under a diffusion mechanism. Under expected repository conditions (Section 6.4.2.3.2), brine migration caused by temperature-dependent solubility will first drive brine towards the waste package. However, these diffusion analyses can ignore the relatively short times required for brine accumulation around the waste package. The analyses assume that all temperature gradients have dissipated and, consequently, the thermally driven brine transport has already occurred. The data used in the analyses consist of an empirical diffusion coefficient and total expected brine volumes accumulated around the waste package (McNulty et al., 1985).

Knauth (1982) gives data for the distribution of water in salt surrounding a brine pocket associated with a sediment inclusion in a salt mine in the Weeks Island salt dome. Knauth (1982) used the vacuum volatilization technique of Knauth and Kumar (1981) to measure the water content of salt specimens sampled at various distances from the brine pocket. An empirical brine diffusion coefficient of 4.9×10^{-12} square meter per second (1.5×10^{-4} square meter per year) is derived from these data when a diffusion process is assumed and the age of isolation of the sediment is assumed to be 75 million years (McNulty et al., 1985). If the sediment were included at the time of deposition of the salt, the age would be greater than 75 million years. However, using lower ages will maximize the diffusion coefficient.

It is known that the mean square of the distance that a particle travels by diffusion from a point source is equal to six times the product of the diffusion coefficient and time. Thus, the mean distance traveled with diffusion coefficient, D, in time, t, is equal to the square root of 6Dt. Thus, with $D = 1.5 \times 10^{-4}$ square meter (1.6×10^{-3} square foot) per year, distances traveled are about 3 meters (10 feet), 10 meters (33 feet), and 30 meters (98 feet) for 10,000, 100,000, and 1 million years, respectively. An additional distance of 15 meters (49 feet) may be added to allow for the disturbed zone. These results indicate that brine moving away from the waste package area by this mechanism will be contained within the host rock for far more than 100,000 years. This theory is also used to estimate the transport of radioactivity in the host rock in Section 6.4.2.4.

Possible Darcian Flow in Host Rock. Ground-water movement through host rock in response to a hydraulic gradient is one of the major factors of interest in defining the expected long-term (postclosure) performance of a repository. Such a movement of ground water is, in part, controlled by the apparent bulk permeability of the host rock and is normally calculated by Darcian flow theory. Although there is little question that salt has void spaces (Lorenz et al., 1981), whether these voids are interconnected is uncertain. The behavior of salt under confining pressures, such as exist at repository depth, tends to close passageways at crystal interfaces. Thus, it is not certain if Darcian flow occurs in intact salt. The following paragraphs assume that it does.

Table 6-36. Estimates for the Disturbed Zone Size

Disturbance	Range
Mechanical	Less than 15 meters (49 feet) (uncertain, depending on mining parameters, site-specific data required)[a]
Chemical	Probably insignificant
Thermo-Mechanical	Disturbance tends to close openings and heal host rock fractures
Thermal-Hydrologic	About 10 meters (33 feet)
Radiation	< 1 meter (3 feet)

(a) On the basis of this discussion, the disturbed zone from all disturbances (excluding thermal) should not exceed 15 meters (49 feet). Mechanical disturbance is a function of the mining and rock parameters. Therefore, when site-specific data are obtained at the repository horizon, mine design and field measurements will determine the amount and impact of the "mechanical" contribution to the disturbed zone.

Experimental determination of rock salt permeabilities has proven problematic. In situ measurements have yielded permeability estimates for salt of 10^{-2} millidarcy to less than 10^{-4} millidarcy (below measurement limit) (Acres American, Inc., 1977, Tables 4 and 5). These measurements were taken from salt pillars within mining excavations. The higher values were measured near the pillar wall and the lower values were measured deeper into the pillar where the salt was less disturbed. Laboratory permeability tests on rock salt indicate that care must be taken in procedure and interpretation because cores are easily damaged and the intercrystalline boundaries relax as the sample is removed from the in situ stress field (Tien et al., 1983, NUREG/CR-3129, p. 209; Baar, 1977).

Performance of Shaft Seals. Preliminary analyses (INTERA, 1985, BMI/ONWI-553, Table ES-4; Gureghian et al., 1983, ONWI-494, p. 41) show that ground-water flow around and through the shaft-seal system will likely be very small. Thus, the shaft-seal system will likely not contribute significant quantities of water to the repository. Final Rule 10 CFR 60.134 states:

> Seals for shafts and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives for the period following permanent closure.

The DOE will demonstrate conclusively that the seal design will function as intended when construction authorization is requested (NRC, 1983, 10 CFR 60.31). The design process will be conducted in concert with performance assessments until a design is achieved that is predicted to function as required. The shaft-seal system will use methods of construction and materials selected to reduce preferential water-flow pathways to meet the requirements of 10 CFR 60.134 (Kelsall et al., 1982, ONWI-411; Burns et al., 1982; Christensen and Hunter, 1981, SAND80-1375). To cause an impact, an unlikely failure must occur within 70 years to provide sufficient ground-water flow, prior to expected creep closure of the backfilled repository, to fill the voids in the crushed salt backfill (INTERA, 1985, BMI/ONWI-553).

Calculations (Gureghian et al., 1983, ONWI-494, pp. 20-31) for a hypothetical repository in the Paradox Basin using generic properties show that the expected penetration time for ground water to reach repository level is at least tens of thousands of years. The order of magnitude of this result is expected to be applicable for a repository at any salt site under consideration. Thus, the likelihood of any ground water reaching the repository storage rooms is reduced. Given the planned sequential emplacement of waste canisters, and backfilling of storage rooms one year after waste has been emplaced (SCC, 1984a, pp. 5-15), creep closure of the repository rooms will be under way before engineered closure of the repository. Placement of bulkheads in the repository will provide a temporary seal until creep closure is complete.

Thus, a successful seal system will not impact the expected performance of a repository in salt. This fact must be conclusively demonstrated during site characterization and other future activities.

Pre-Waste-Emplacement Ground-Water Travel Paths and Travel Times. The geologic and hydrologic information available to define the ground-water flow regime in the vicinity of Richton Dome is presented in Sections 3.2 and 3.3. This information has been used to develop regional and local (near-dome) conceptual models of the ground-water flow regime to evaluate the probable pathways for radionuclides that may be released from the dome. These models (INTERA, 1984, ONWI-502; Metcalfe and Andrews, 1984; Ertec, 1983, ONWI-456; ETC, 1985a) address the sensitivity of the expected ground-water flow directions in the vicinity of the dome for uncertain hydrogeologic parameters. The principal conclusions for the Richton Dome of these studies include the following:

1. The expected regional discharge area(s) for the deep confined aquifers (i.e., Upper Claiborne and Wilcox) is uncertain due to the uncertainty in the horizontal permeability of the aquifers and the vertical permeability of the aquitards (i.e., Lower Claiborne and Vicksburg-Jackson) downgradient from the dome.

2. The vertical flow direction along the dome flanks is uncertain due to the uncertainty in the vertical permeability along the flanks. Possible travel paths outside the salt dome are (1) upward along the dome flanks to the upper aquifers, (2) laterally within the Upper Claiborne and upward across the Vicksburg-Jackson to the upper aquifers, or (3) laterally in the Wilcox upward across the Lower Claiborne, laterally and upward in the Upper Claiborne, and upward across the upper aquifers.

3. The expected ground-water travel path and travel times within Richton Dome are uncertain due to the uncertainty in the permeability, porosity, and hydraulic gradients within the dome.

For evaluations of pre-waste-emplacement travel times, the edge of the dome is considered to be the accessible environment. The ground-water travel path outside the Richton Dome is a function of the permeability of the varying lithologies within and surrounding the dome and of the horizontal and vertical hydraulic gradients within the dome and in the strata surrounding the dome. As all these values are uncertain, the expected travel path and travel time along this path are also uncertain. To address the basis for evaluating several aspects of the Geohydrology guideline (10 CFR 960.4-2-1, Section 6.3.1.1), first the travel time from the disturbed zone to the edge of the salt stock of the dome is calculated, and the characteristics of flow outside the dome are generally described.

Under expected conditions, the movement of radionuclides by diffusive processes may be several meters. To address the requirements of the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment, a conservative assumption was made that the salt stock is a porous medium. With the assumption of Darcian flow, 1,000 simulations were conducted (Andrews et al., 1985) using the code PTRACK (Thompson et al., 1985). The geohydrologic properties (permeability, porosity, and hydraulic gradient) for each simulation were sampled (using the Latin Hypercube method) from observed, published, or modeled result ranges of each variable and their distributions. The input data distribution and analyses are summarized below. The details of the analyses are described by Andrews et al. (1985).

For ground-water travel time analyses, the buffer zone is considered as a homogeneous salt mass. It is the intent to leave at least 244 meters (800 feet) of undisturbed salt between the edge of the disturbed zone and the flanks of the dome. This is the buffer zone. Anomalous features of the examined salt domes, in general, appear to be less frequent and pervasive in the interior than in the exterior Gulf Coast salt domes, and varying conditions exist among interior domes. Major anomalous features have not been identified in the salt stock at Richton Dome and, from mining experience in other interior salt domes, they are not expected to occur at Richton Dome. Certain features, such as coarsely crystalline salt, highly deformed salt layers, and inclusions of gas or brines, may be encountered.

Based on mining experience, it should be feasible to predict their existence based on stratigraphy and salt characteristics (Section 3.2.3.2.4).

The uncertainty associated with defining the permeability of salt is described in Section 6.3.1.1.1. For the purpose of this analysis, the permeability of Richton Dome salt is considered to be log normally distributed with a range from 10^{-2} to 10^{-7} millidarcys. The maximum value of this range captures the maximum observed values determined from laboratory tests conducted at in situ confining pressures where brine was used as the permeant as well as the maximum observed in situ values.

The porosity distribution utilized in the analysis of travel times in Richton Dome is based on salt porosities determined from resistivity logs of bedded salt in the Palo Duro Basin (Andrews et al., 1985). A normal distribution has been assumed with a minimum porosity of 0.3 percent, a mean of 0.97 percent, and a maximum of 1.64 percent. The generally accepted *positive correlation* between permeability and porosity has not been incorporated in the travel time calculation. Ignoring such correlations results in a travel time distribution having lower and higher extremes and indicates a conservative assumption from the perspective of an expected performance.

The horizontal gradient within Richton Dome is assumed to be similar to the gradients in the more permeable strata surrounding the dome. Modeled gradients in the Sparta aquifer average about 0.0012 (Metcalfe and Andrews, 1984; Ertec, 1983, ONWI-456) while modeled gradients in the Wilcox aquifer average about 0.0002 (INTERA, 1984, ONWI-502; Metcalfe and Andrews, 1984; Ertec, 1983, ONWI-456). In order to be conservative and to appropriately represent the uncertainty associated with these modeling results, six horizontal gradients ranging from .0015 to .0085 have been utilized in the travel time assessment. The gradients are assumed to be normally distributed.

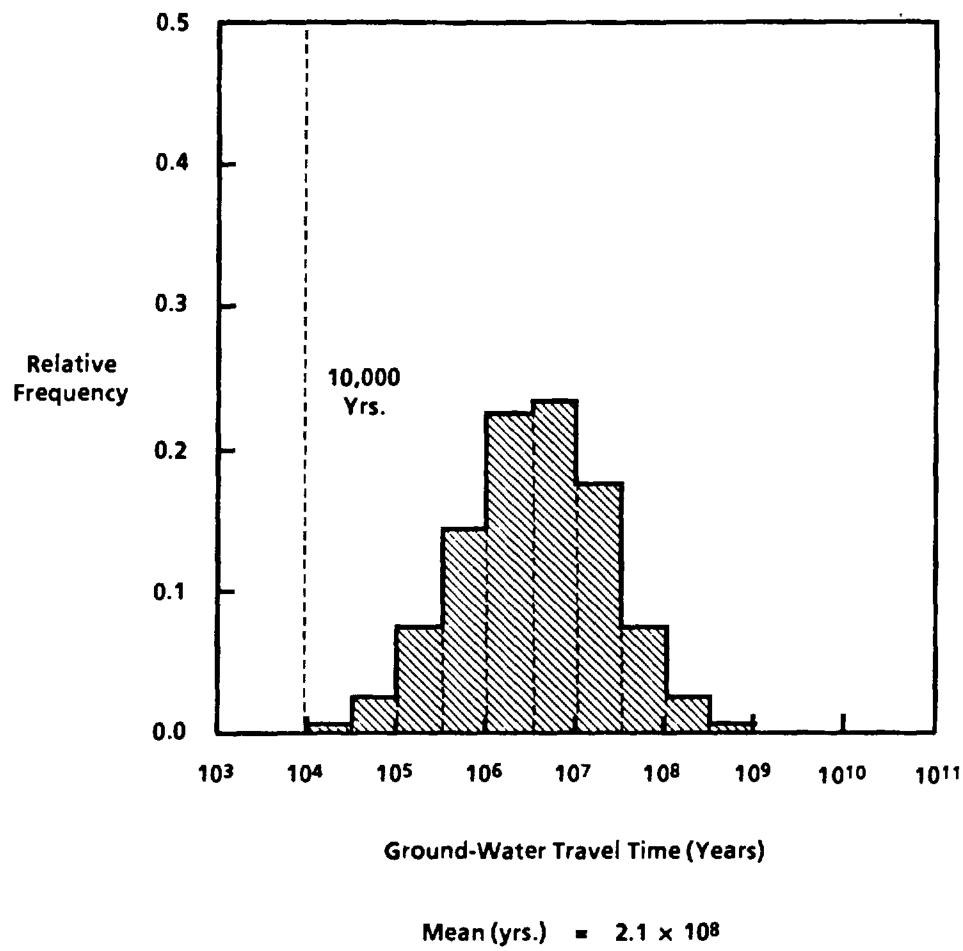
The above distributions have been sampled for 1,000 realizations (representations of the ground-water system by selecting combinations of geohydrologic parameters) for the travel-time estimates from the disturbed zone to the edge of Richton Dome. The travel time histogram and Complementary Cumulative Distribution Function (CCDF) for the travel time are illustrated in Figures 6-19 and 6-20. Figure 6-21 is a schematic representation of the buffer zone used for travel time estimates. The probability of a travel time being less than 1,000 or 10,000 years is less than 0.001 (based on 1,000 realizations). That is, there are no observed travel times to the edge of Richton Dome less than 10,000 years in 1,000 trials. The mean travel time (2.1×10^8 years) is considered to describe the expected condition, while the median travel time (3.5×10^7 years) is also a measure of central tendency and is a more conservative value.

The above pre-waste-emplacement ground-water travel times through the buffer zone (under the conservative assumption that salt is a porous medium with extreme ranges of permeability, porosity, and hydraulic gradient) meet the travel time criteria of 10 CFR Part 60 by a substantial margin of safety.

The general ground-water flow regime outside of Richton Dome as modeled (INTERA, 1984, ONWI-502; Ertec, 1983, ONWI-478; and ETC, 1985a) has the following characteristics. Regional ground-water flow in the Upper Aquifer is strongly influenced by topography. Recharge corresponds to areas of topographic highs while discharge occurs to the major rivers of the region (Leaf River, Black Creek, Pearl River, and Chickasawhay River). Refining the modeled region to evaluate the flow around Richton Dome generated an Upper Aquifer potentiometric surface in which discharge to smaller drainage systems in the vicinity of the dome also occurred (e.g, Bogue Homo Creek, Thompson Creek, and Tallahalla Creek). A generalized description of these ground-water modeling results is given in the next two paragraphs.

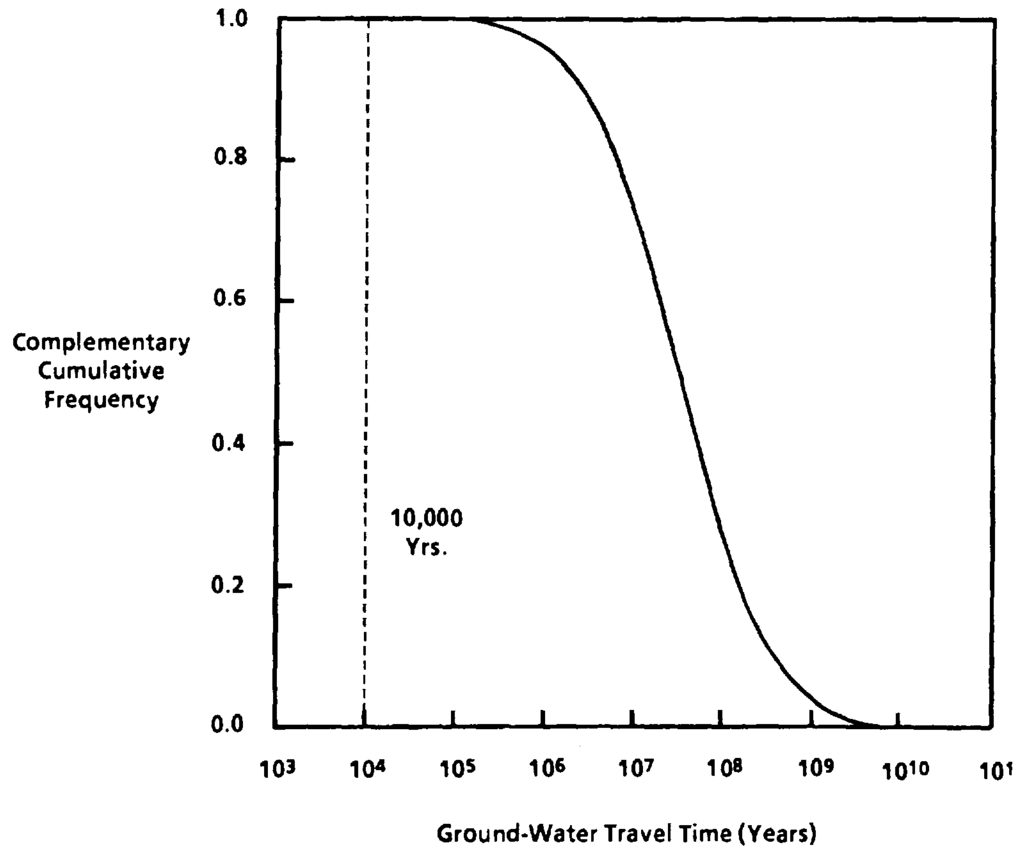
Regional precipitation upon the outcrop of these rock units is the main source of recharge. In the area of outcrop, the ground water is unconfined and most of the recharge is discharged to streams. The remaining volume moves down into the confined portion of the aquifer, as evident from the hydraulic gradient. This fluid continues to flow down overlying or underlying confining units. The relative volumes of water leaking across the confining units as compared to that volume continuing downdip is dependent on the hydraulic conductivity contrast between the transmissive aquifers and the low conductivity aquitards. If the confining units have a sufficiently low vertical hydraulic conductivity, then the regional flow will not be impacted by the potential in the overlying strata. However, if there is less confinement provided by the aquitards, the flow in the aquifers will be more strongly governed by the flow regime in the overlying aquifers.

While the ground-water flow is predominantly horizontal through the aquifers in the Richton Dome region, the flow through the aquitards is generally vertical. The simulated areas of upward and downward flux are controlled by the particular parameterization employed in the conceptual model. The extent of upward flow across the Vicksburg-Jackson aquitard is in part controlled by the horizontal conductivity variability in the Upper Claiborne aquifer; it is also controlled by the southern boundary condition applied to the Wilcox aquifer (INTERA, 1984, ONWI-502, Section 3.3.2.1). This boundary condition affects the upgradient heads in the Wilcox aquifer, which in turn dictate the vertical flow direction. It is apparent from the figures presented by INTERA (1984, ONWI-502, Figures 3-4, 3-5, 3-7, and 3-9) that the vertical flow directions across the aquitards in the vicinity of Richton Dome is a function of the particular parameterization. Currently available data can support several different conceptualizations of the regional ground-water flow regime. These conceptualizations must be treated with some uncertainty until the data collection by detailed site characterization is completed.



Relative Frequency of Pre-Waste
Ground-Water Travel Times
Richton Dome

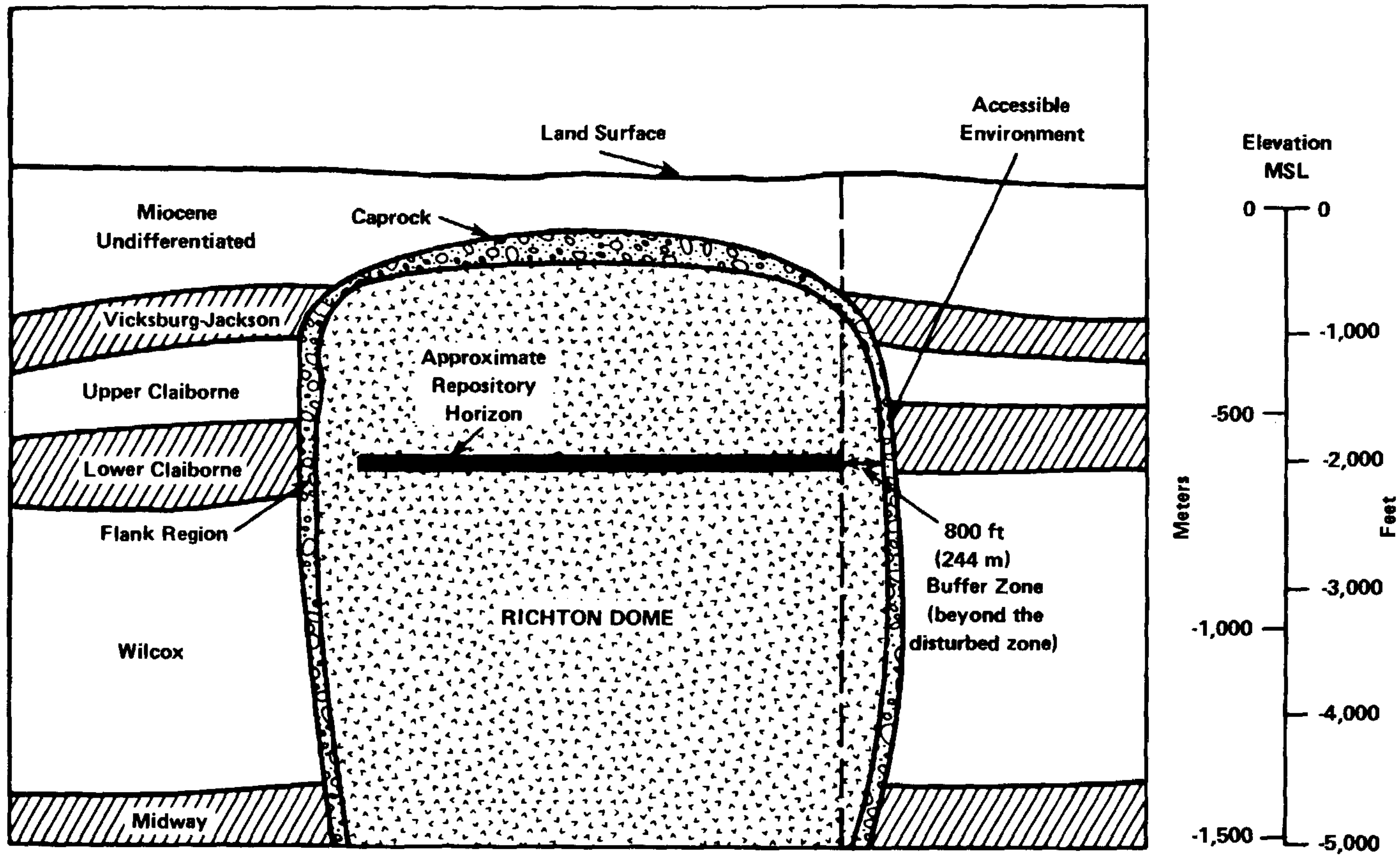
Figure 6-19



95th Percentile (yrs.) = 1.5×10^6
50th Percentile (yrs.) = 3.5×10^7
5th Percentile (yrs.) = 6.8×10^8

Complementary Cumulative Frequency of Pre-Waste Ground-Water Travel Times Richton Dome

Figure 6-20



Note: The schematic cross section shows position of accessible environment for local model evaluations.

Cross Section of Richton Dome

Figure 6-21

Conclusion. Considering the conceivable processes of ground-water or brine transport, it appears that fluids do not leave the host rock for in excess of 10,000 years. Assuming salt is a porous medium and considering the ranges of the hydrogeologic parameters (permeability, porosity, and hydraulic gradient) the pre-waste-emplacement ground-water travel time from the repository to the edge of Richton Dome exceeds the requirements of 10 CFR Part 60.

6.4.2.4 Preliminary System Performance Assessment

The isolation system consists of the waste package (Section 6.4.2.2.1), engineered barrier (repository) (Section 6.4.2.2.2), and geologic (Section 6.4.2.2.3) components (subsystems) acting in concert as a system. The performance of individual subsystems is described in Section 6.4.2.3. The performance of the isolation system is described in this section from the system viewpoint.

6.4.2.4.1 Reference Case. Under reference (expected) conditions, waste packages in salt repositories will not fail for a very long time and radioactivity will not be released from the repository. The calculations in Section 6.4.2.3.3 suggest that waste packages for the Richton Dome site will last indefinitely. The only mechanism expected to act on the package is uniform corrosion from brine, which migrates to the waste package from inclusions throughout the salt. This migration is due to thermal diffusion enhanced by temperature-dependent solubility. The total volume of brine that can reach the package is limited because brine migration ceases when thermal gradients from emplaced waste no longer exist. This volume is not sufficient to corrode through the overpack. Thus, with no release from the package for an indefinite period to provide a source term to the repository and geologic subsystems, all 10 CFR Part 60 and 40 CFR Part 191 requirements would be automatically met. No release to the accessible environment is expected for at least 100,000 years because of the small expected transport distances in salt after package failure. No radioactivity is expected to be added to any aquifer until beyond 100,000 years.

The sensitivity of the system to early failure of packages can be tested by assuming early failure. The potential source terms for CHLW and SFPWR for the geologic subsystem are shown in Tables 6-32 and 6-33, respectively, as multiples of the EPA limits for individual nuclides. These results were determined assuming no waste form resistance and that nuclides dissolved in the available brine according to solubility limits given in Table 6-32. These tables show that, even in the case of a hypothetical package failure as early as 300 years, the EPA site limits (40 CFR Part 191) are met at the package boundary, excluding Cs-137. There is no requirement that the EPA site limits be met at the package boundary. Travel times are such that Cs-137 will decay sufficiently to meet the EPA standards prior to reaching the accessible environment. The following sections describe results with variation in subsystem performance. These results demonstrate the impact of uncertainties in subsystem performance.

6.4.2.4.2 Performance Limits Case. This case is used to illustrate the capability of the geologic setting to restrict releases to the accessible environment in the event the waste package or engineered barrier subsystems just barely meet regulatory requirements. A waste package lifetime of 300 years and engineered barrier release of 10^{-5} per year of 1,000 year inventory, i.e., just meeting 10 CFR Part 60 requirements, are assumed.

For the undisturbed performance of a salt site, there are only two plausible mechanisms for radionuclide transport away from a failed waste package: (1) diffusion of radionuclides, and (2) radionuclides dissolved in brine, which migrates away from the waste package. The first mechanism is driven by the concentration gradients of the radionuclides in the solid salt while the second mechanism is driven by the concentration of brine in the solid salt.

The initial transport of brine is toward the waste package due to thermal gradient brine inclusion migration. However, after the temperatures have decayed to near ambient levels, any brine transport will be away from the waste package. The model used in this report considers brine transport away from the package to be due to the second mechanism described above. Diffusion with an enhanced empirically determined coefficient is used to describe this transport. The time periods during which the brine accumulates and then migrates away from the package are relatively short compared to the time periods of interest. Consequently, the entire release from the package is assumed to occur at package failure. The amount of the release may be limited by the release fraction from the waste form and the solubility of the radionuclide in the brine since the amount of brine that accumulates is also relatively small. When the brine concentration decreases with distance from the waste package, the brine concentration gradient can drive brine containing radioactivity into the surrounding salt. To describe the mobility of particles, atoms, molecules, etc., by random molecular motion, Fick's equation (Crank, 1975, p. 2) for diffusion has classically been used. Implicitly, these calculations ignore advective transport due to a hydraulic gradient. As discussed in Section 6.4.2.3.5, the host rock has a very low, if not zero, hydraulic conductivity and the assumption of a Darcian flow model also gives short travel distances.

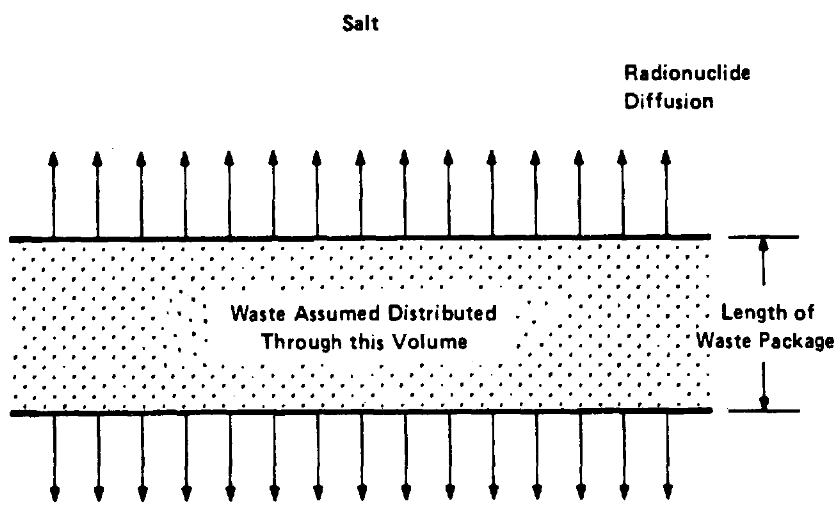
Calculations for pure diffusion can use diffusion coefficients calculated from a theoretical basis. However, in other applications, Robertson (1974) showed that diffusion theory can successfully model "dispersion" of radioactivity in ground-water systems with empirical diffusion coefficients. Thus, in this analysis we use the diffusion theory to empirically determine brine "diffusion" coefficients based on the water content of field samples of salt that were obtained at various distances from a water-bearing sediment inclusion in salt. These coefficients should apply for transporting dissolved radionuclides since the resultant brine "diffusion" coefficient is about four times larger than solid state diffusion coefficients, which would apply if the radionuclide elements were to separate from brine and diffuse through salt by themselves. Additional discussion of this factor is given in succeeding paragraphs. Consequently, the diffusion analyses used these empirical brine "diffusion" coefficients to estimate the movement of radionuclides in a nuclear waste repository in salt. The analyses assumed an infinite plane source as shown in Figure 6-22 to represent the nuclear waste repository.

Analytical Approach. McNulty et al. (1985) give the equations that govern the transport of brine away from the waste package for a diffusion mechanism using an empirically determined coefficient. This diffusion analysis for radionuclide transport ignores the relatively short times required for brine accumulation around the waste package. The analysis assumes that the thermally driven brine transport has already occurred and that the waste package releases radionuclides immediately after its failure.

To maximize the calculated curie release, the analysis assumes that all mass transfer occurs vertically as shown in Figure 6-22. In addition, the analysis does not account for the chain decay of uranium-234 and assumes all uranium-234 immediately becomes radium-226. Integration of the diffusion fluxes over intervals of 10,000 years at several distances from the release point allows direct comparison with 40 CFR Part 191 as if the distances chosen were different selected boundaries of the accessible environment.

Data Base and Uncertainty. The data used in the analyses consist of an empirical diffusion coefficient, radionuclide inventories and solubilities (Jansen, 1985), and total expected brine volumes (McNulty et al., 1985). Knauth (1982) gives data for the distribution of water in salt surrounding a brine pocket associated with a sediment inclusion in a salt mine in Weeks Island dome. These data give an empirical brine diffusion coefficient of 4.9×10^{-12} square meter per second (1.5×10^{-4} square meter per year) when a diffusion-like process is assumed (i.e., the data are fit to a solution of the diffusion equation) and the time of entrapment of the sediment is assumed to occur 75 million years ago (McNulty et al., 1985).

In contrast, Jost (1960, p. 184) shows that transport by ordinary solid state diffusion of sodium ions in salt occurs very slowly. Jost's correlation gives a diffusion coefficient of about 3×10^{-16} square meter per second (9.5×10^{-9} square meter per year) for 300 C (572 F), which is higher than the maximum expected repository temperature (Section 6.4.2.3.1). The empirical brine diffusion coefficient is four times larger than the one given by Jost (1960). Consequently, the diffusion analyses use the brine diffusion coefficient, which gives penetration distances about two times larger than calculated penetration distances based on solid state diffusion of sodium ions in salt.



Schematic of Repository as
Infinite Plane Source

Figure 6-22

Source: McNulty et al., 1985.

Diffusion Analyses and Results. McNulty et al. (1985) made separate diffusion calculations using brine volumes and curie inventories specific to CHLW and SFPWR waste and assuming a 300-year package life and 10^{-5} per year waste form release rate. The analyses show that the total 10,000-year curie release would exceed the EPA standard quantities for a maximum penetration distance less than 1 meter (3 feet). In addition, Figure 6-23 shows that after 100,000 years, the most soluble radionuclides, iodine-129 and cesium-135, would have traveled less than 10 meters (33 feet). These transport distances are negligibly small. The disturbed zone is of the order of 15 meters (49 feet), as described in Section 6.4.2.3.5. As shown by Figure 6-23 the maximum penetration front for radionuclide transport of any element from any waste type during 100,000 years is less than 10 additional meters (33 additional feet). Thus if 25 meters (82 feet) thickness of host rock including the 15-meter (49-foot) disturbed zone is available all around the repository, it is likely that radioactivity will not escape the host rock for over 100,000 years even assuming package failure. The transport at the location (less than 1 meter [3 feet]) where the EPA standard is satisfied is principally I-129, Cs-135, and Cs-137.

6.4.2.4.3 Sensitivity of Performance to Variations in Release from the Engineered Barrier System. Clearly, reduction in the fractional release from 10^{-5}/year to 10^{-6}/year with a 300-year package would proportionately reduce the small transport quantities of I-129, Cs-135, and Cs-137 described in the previous section. The small quantities (about a total 0.0002 of the EPA limit) of other nuclides are not reduced because the solubility limit continues to be the factor controlling their release.

Increasing the fractional release rate to 10^{-4} of the 1,000-year inventory per year would cause the release from the engineered subsystem to the geologic subsystem of all of the I-129 and Cs-135 in about 10,000 years because the solubility limits of these nuclides are very large and decay is not a factor for I-129 and Cs-135 in the 10,000 years. This, in turn, will cause the location at which the EPA standard is satisfied to move outward from that reported in Section 6.4.2.4.2. However, the EPA standard is still met with less than 1 meter (3 feet) of host rock. Figure 6-23 is reasonably valid for this consideration.

6.4.2.5 Comparison with Regulatory Criteria

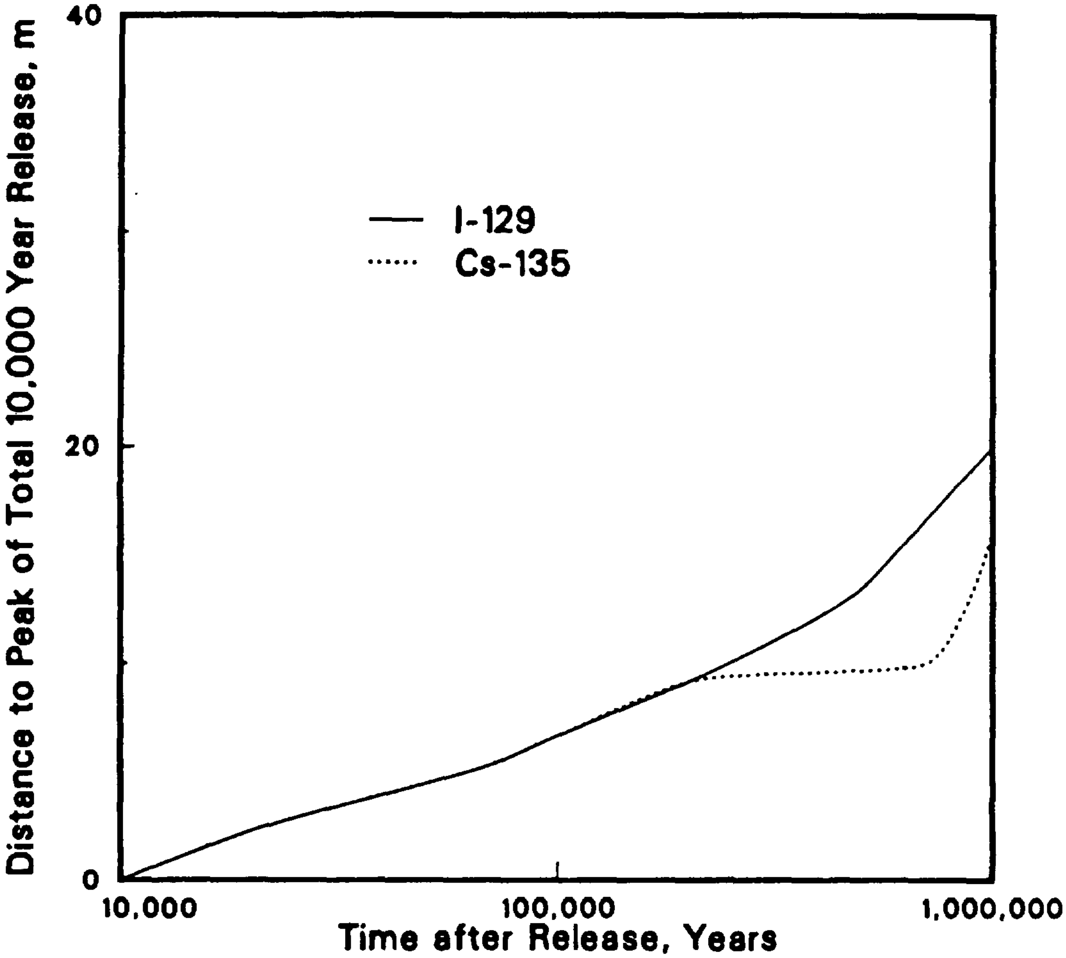
Table 6-37 compares the calculated results described in the immediately preceding sections for the cases considered with regulatory requirements and also gives results for 100,000 years (10 CFR Part 960). The expected package lifetime far exceeds the 1,000-year time frame specified by the ground-water contamination and individual protection requirement of 40 CFR 191 so that no contamination of ground-water or dose to individuals is anticipated regarding these requirements as noted in the table. These calculations indicate that the expected condition is that all standards will be met. This is obvious except for the ground-water travel time requirement because of the long expected waste package lifetime.

The performance limits case demonstrates that the site is fully capable of meeting the requirements on release to the accessible environment (40 CFR Part 191) with engineered subsystem performance just meeting regulatory requirements. The Cs-137 release requirement could be met with a package lifetime of 750 years for SFPWR and 760 years for CHLW (with no waste form resistance). Alternately, if a 10^{-4} release (ONWI, 1983, ONWI-462, p. 11) is specified, a package lifetime of 360 years will provide all requirements as discussed in Section 6.4.2.3.4.

6.4.2.6 Effects of Potentially Disruptive Events and Processes

Section 6.3 considers maximum (conservative) rates for geologic and hydrologic processes to evaluate the suitability of the site with respect to the guidelines. Earlier parts of Section 6.4.2 model the performance of repository systems also assuming maximum (conservative) rates. Additional, unanticipated, events that could disrupt the repository would be due either to geologic processes or human interference.

6.4.2.6.1 Geologic Processes. The energy driving geologic systems comes from the earth (tectonics) and the atmosphere (climate). The effect of large, unanticipated changes in the climate and increases in the rate of tectonism are discussed below.



Source: McNulty et al., 1985.

Travel Distances with Time at Richton Dome for Most Soluble Radionuclides, Iodine – 129 and Cesium – 135

Figure 6-23

Table 6-37. Performance Assessment Results

Regulatory Requirement	Expected Performance Level: Reference Case (Expected Condition)	Performance Limits Case: 300-Yr. Pkg. 10^{-5} Release	Sensitivity Analyses: 300-Yr. Pkg. 10^{-6} Release	Sensitivity Analyses: 300-Yr. Pkg. 10^{-4} Release
Contamination of Major Ground Water Source (40 CFR Part 191)	0	0	0	0
Dose to Individual for First 1,000 Years After Closure[a]	0	0	0	0
Ground Water Travel Time (10 CFR Part 60)	maximum 10,0000-year travel distance = 20 m; therefore requirement is met if accessible environment is selected greater than 20 m plus disturbed zone allowance (15 m) or a total of about 35 m from repository			
Package Lifetime 300 to 1,000 years (10 CFR Part 60)	10,000 yr.	Specified 300	Specified 300	Specified 300
Engineered Subsystem Release (10 CFR Part 60)	0	Specified to meet	Specified to meet	All but Cs-137[b]
Release to Accessible Environment (40 CFR Part 191)	0	meets release requirements in less than 1 meter beyond disturbed zone		
Release to Accessible Environment After 100,000 years	0	0	0	0

(a) Individual protection requirements given in 40 CFR Part 191.

(b) The 10^{-4} fractional release does not automatically cause violation of the 10^{-5} 10 CFR Part 60 requirement because of solubility limitations. All nuclides except Cs-137 with solubility limits and 10^{-4} package release then meet the 10^{-5} requirement.

Climate. The plausible extremes of climate experienced in the Gulf Coast area during the Quaternary are described in Section 3.2.2.3. These were alternating pluvial episodes (periods of high rainfall and cool temperatures) accompanying glaciation to the north, and intervals characterized by hot and dry conditions accompanying the interglacial conditions. These conditions are expected to recur several times during the next million years. The effects of climate on the hydrologic conditions and erosional processes are considered to be negligible. However, there are insufficient data to evaluate the influence of climatic change on salt dissolution. The analysis of salt dissolution in Section 3.2.5.7 estimates Quaternary dissolution rates based on caprock development and characteristics of overdome stratigraphy.

The presence of caprock at Richton Dome (Section 3.2.3.2) is indicative of past dissolution of anhydrite caprock forms by residual accumulation, rather than by precipitation of anhydrite from fluids around the dome (Section 3.2.7.2). The history of caprock formation at Richton Dome has been interpreted based on stratigraphic and structural data compiled from sulfur exploration wells, area characterization borings, and geologic mapping (Werner, 1984). The caprock at Richton Dome may have begun forming as early as middle to late Eocene time (38 to 45 million years ago), and appears to have been completely formed by late Oligocene time (24 to 30 million years ago). Since late Oligocene there has not been significant hydrologic communication through the caprock. Similarly there has not been significant dissolution of the top of the salt stock since late Oligocene, as evidenced by the smooth, arched form (free of structural collapse) of the caprock and several overlying sedimentary units (Werner, 1984).

Tectonics. Tectonic activity in the Gulf and surrounding uplifts has diminished since the Pennsylvanian Period. There is no reasonable basis for anticipating that a repository would be disrupted by the development of new faults or other structures. It is not known whether regional uplift is continuing. Uplift rates characteristic of orogenesis are neither observed nor anticipated because the site is distant from any modern lithospheric plate margin. The highest known long-term rate of epeirogenic uplift is 5.2×10^{-4} meter per year (1.7×10^{-3} foot per year) associated with the Colorado Plateau (SWEC, 1978, ONWI/SUB-E512-00600/1). This greatly exceeds what plausibly can be expected in the Gulf area. However, even if it is assumed that these conditions could arise and continue in the region during the next one million years and that river incision could keep pace with uplift, the repository would not be exhumed.

Seismicity is discussed in more detail in Section 3.2.5.2. The nearest earthquakes have been a 1975 shock, MMI IV, approximately 75 kilometers (45 miles) south-southwest of the site, and a 1978 shock, MMI V, approximately 75 kilometers (45 miles) north-northeast of the site. Neither earthquake occurred within the tectonic setting within which Richton Dome is located. The maximum historical shaking experienced at the site is estimated to have been MMI V to VI, and resulted from the 1811-1812 New Madrid, MS, earthquakes (Nuttli, 1973, p. 230).

Several faults are present in the region around the site (see Section 3.2.5.1). Available data indicate these faults have not been active in the Quaternary, although conclusive evidence to prove lack of movement has not been developed for some faults such as the Phillips, F-7, and F-9. No seismically active tectonic structures within the geologic setting are indicated by the historical earthquake data. No historical earthquake has had associated surface fault rupture. The nearest possible correlation between seismicity and tectonic elements is the general spatial correspondence between earthquakes in Clarke County, Mississippi, and at Melvin, Alabama, and the Pickens-Gilbertown Fault System. However, the significance of this possible correlation is speculative because of (1) inexact epicenter locations, and (2) the possible influence of active hydrocarbon production.

The maximum earthquake that might occur at random locations in the region (i.e., from undetected subsurface faults) was estimated as Richter magnitude 5.3. Near the epicenter, shocks of this magnitude could produce MMI VI and perhaps VII, and accelerations on the order of 14 percent of gravity.

The repository will be designed to operate assuming these maximum earthquakes. Even larger earthquakes would not affect the backfilled (postclosure) repository.

6.4.2.6.2 Human Interference. Regulatory Requirements. Human activities give rise to another group of possible disruptions. These disruptions are addressed, in a general manner, by the system guideline of 10 CFR Part 960, Paragraph 960.4-1:

> 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.

Human interference is then addressed directly by Paragraph 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 ... .

Implementation of Regulations. To date, the NRC Regulation (10 CFR Part 60) referred to in the System Guideline has received relatively little attention in the performance assessment literature. Such analyses need to be site specific and sites are not yet chosen. However, the cumulative release requirements of the EPA Standard for the complete disposal system (40 CFR Part 191, Paragraph 191.13) have received greater attention, even to the extent that a methodology has evolved that is specially adapted for showing compliance with the EPA Standard.

To implement this methodology with respect to human interference, those human activities are specified that could potentially compromise the performance of a repository. Then, using a rather rigorous procedure, these activities are coupled conceptually with other features, processes, and events, which may be highly site specific, to form scenarios. The brine-pocket-hit scenario, to be considered subsequently, is an example. Here the human activity of drilling through the repository is coupled with a system feature, a brine pocket with near lithostatic pressure lying directly beneath the repository. The study of Arthur D. Little (1980) provides a very thorough discussion of many features, processes, and events. Bingham and Barr (1979, SAND78-1730) show how such phenomena are coupled conceptually by the use of event trees. Cranwell et al. (1982, SAND81-2573) and Cranwell et al. (1982, SAND80-1429) then apply the complete methodology. The latter authors employ statistical techniques to account for parameter uncertainties and scenario probabilities in a procedure that permits direct comparison with the EPA Standard.

A variant of the above methodology likely will be adopted for the site characterization program, where data will be sufficient to support site-specific analysis. Here, however, to support a nomination for site characterization, the objective is somewhat more limited, and such a site-specific analysis, though desirable, is not yet credible because of lack of site-specific data. The objective in this report is to show, in accordance with 10 CFR Part 960, Appendix III, that the available evidence does not support a finding that the site is not likely to qualify under Paragraph 960.4-2-8-1(a). Site-specific data and analyses will be required for formal site nomination. Furthermore, issues to be identified below will be dealt with during the site characterization program. However, the literature for generic sites and certain specific locations, different from the site that is the subject of this report, is sufficiently extensive at this time to permit a plausible argument in favor of nomination for site characterization.

Release Scenarios. Many different features, processes, and events can conceivably affect the operation of a nuclear waste repository, as illustrated by the comprehensive lists of Burkholder (1980) and Koplick et al. (1982). Scenarios formed from such phenomena have been developed and examined for more than a decade. Although most such studies focus on bedded salt, many of the conclusions are transferable to a domed-salt lithology. The work of Claiborne and Gera (1974, ORNL/TM-4639), and others, indicates that some of the phenomena will be sufficiently improbable that they will not significantly contribute to risk. Burkholder (1983, ONWI-286), in fact, notes "an emerging consensus that scenarios involving meteorite impacts, sabotage, nuclear warfare, erosion, criticality, volcanism, diapirism, stored energy release, and natural salt dissolution are unimportant ... to the performance of nuclear waste isolation systems." Certainly no scenarios will be excluded a priori from a site-specific analysis. However, the literature strongly suggests that such scenarios will be insignificant contributors to risk.

At the same time, however, there remain inconsistencies in the literature regarding certain human intrusion scenarios that will require additional analysis. These inconsistencies relate, to a lesser extent, to ground-water transport scenarios, and to a greater extent, to direct-access scenarios. Pepping et al. (1983, SAND82-1557) analyzed several U-tube type ground-water transport scenarios and found a strong dependence on source characterization. For those cases in which the entire repository, or even one entire room, was exposed to the invading fluid, with an assumed leach limitation, the radionuclide release limits of a draft version of the EPA Standard 40 CFR Part 191 were slightly exceeded. However, when a mixing-cell model was used with a solubility-limited source, releases were negligible with respect to the standard. The fact that the EPA standard was exceeded in some cases is not considered to be significant since the aquifer transmissivities of this generic bedded-salt site were unrealistically high. Further, the study was designed to illustrate risk methodology rather than to evaluate a real site against the EPA standard. The results are significant, however, in two respects, both of which are noted by the authors. First, the need for realistic modeling of the engineered barrier and the waste package is indicated so that the source term may be determined more precisely. Second, a need for more precise modeling of the borehole is also indicated. This analysis assumes that the boreholes stay open in excess of 10,000 years, whereas, salt creep quite possibly will close the boreholes to fluid flow within a relatively short period of time.

Pepping et al. (1983, SAND82-1557) also analyzed two direct access scenarios, namely a direct-canister-hit scenario and a brine-pocket-hit scenario. For the former, it was arbitrarily assumed that one-fourth of the canister contents were removed each time a canister was penetrated. For the latter, another rather arbitrary source-term assumption was adopted. The fraction 1/40 of the contents of one room was released over a time period of 100,000 years. For both scenarios the location of the borehole was treated probabilistically. The authors note that "the penetration scenarios (direct-canister-hit and brine-pocket-hit) indicate potentially serious consequences." However, the possibility of a sudden and catastrophic failure of waste packages has since been considered. Harper and Raines (1985, p. 499) considered a direct hit scenario and analyzed stochastically the release of radionuclides to the environment. This study showed that there was a high expectation that EPA requirements would be met with a repository in salt. INTERA (1985, BMI/ONWI-553) analyzed the intrusion of a borehole into the repository and calculated the subsequent dissolutioning and radionuclide releases to the accessible environment. INTERA (1985, BMI/ONWI-553) overestimated borehole flow rates, ignored any containment by the waste package, and ignored the likely plugging of the borehole by silt or other materials to give added conservatism to the calculations. Still, releases were below draft EPA (1982b) standards when the accessible environment was assumed to start at 10 kilometers (6.2 miles). Monti and Gupta (1984) analyzed an abandoned or undetected borehole and found that the maximum potential dissolution in one case would increase the borehole diameter to 2 meters (6.5 feet) from a 0.34 meter (13-inch) diameter before creep closure ultimately closed the borehole. Therefore, they concluded that salt dissolution in existing boreholes for the case considered would not provide a pathway for radionuclide release.

In the WIPP Safety Analysis Report (DOE, 1983b), six different scenarios were analyzed. It is interesting to note that in all of these scenarios, including the three analyzed by Pepping et al. (1983, SAND82-1557), the consequences were found to be insignificant. The whole body dose commitment was found, in all cases, to be less than the recommended dose limit of 500 millirems per year. Consequences were not compared with the EPA Standard in this study. The major difference between the two analyses is threefold. First, in the U-tube scenario, "the dissolution of radioactive waste is assumed to be controlled only by salt dissolution in the waste storage area with no credit taken for the waste containers" (DOE, 1983b). Second, for the direct access scenarios, the presence of a mud pit is characterized for the drilling operation, along with drying, resuspension, and atmospheric transport of radionuclides. Third, and finally, for the brine-pocket hit, it is also assumed that the flow of brine is shut off after 24 hours of release. It is not proposed here that the mud pit and atmospheric transport be considered in further scenario refinement since the status of such an assumption with respect to the EPA Standard is questionable. However, further characterization of the source term for ground-water transport, brine-pocket-hit and direct-canister-hit scenarios are desirable and will be considered during site characterization.

ONWI (INTERA, 1985, BMI/ONWI-553) analyzed a U-tube connection between a single borehole (inadvertently drilled or abandoned before construction of repository), a repository storage room, and an access shaft that still offered a potential hydraulic connection despite being backfilled and plugged. The analyses maximize the predicted releases by assuming the hydraulic connection remained open for 10,000 years. Pressure boundary conditions were provided from a regional hydrologic analyses. The flow was calculated in a local flow model taking into account density variations due to increased salinity of the water in the salt units and the increased temperature due to the generation of heat by the radioactive waste. ONWI (INTERA, 1985, BMI/ONWI-553) showed that predicted releases from a U-tube connection were several orders of magnitude lower than draft EPA (1982b) standards when the accessible environment starts at 10 kilometers (6.2 miles). Future site-specific analyses for site characterization will calculate releases at distances much closer to the point of radionuclide release.

Harwell et al. (1982, PNL-2955) examined a salt-solution mining scenario, the cavern for which intercepted the repository. The host formation was considered to be the Hainesville Dome of the East Texas Salt Dome Basin. The probability of such a scenario, of course, would be higher for a dome than for a bedded-salt site (Burkholder, 1980). It was assumed that the mine produced 9.08×10^5 metric tons (1 million tons) of salt per year and operated for up to 50 years without detecting radioactivity. It was further assumed that three percent of the salt was ingested with an average rate per person of 1,800 grams (63 ounces) of salt per year. The consequences were presented in various ways, among which was a 70-year individual dose to the whole body resulting from a one-year period of ingestion. Results varied depending on the time from repository closure. They exceeded background by three orders of magnitude at 100 years postclosure and by one order of magnitude at 1,000 years postclosure (Harwell et al. 1982, PNL-2955). A comparison with the EPA Standard was not performed.

An ONWI task force (ONWI, 1981, ONWI-320[1]) examined the same basic scenario. Consequences, as determined by this study, were much less severe. For a 70-year individual dose to the whole body resulting from a 1-year period of ingestion, results were approximately equal to background at 100 years postclosure and were about two orders of magnitude less than background at 1,000 years postclosure, i.e., the results here were less than those obtained in the study of Harwell et al. (1982, PNL-2955) by three orders of magnitude. Again, consequences were not compared with the EPA Standard. One significant difference between the two calculations is the assumed level of preferential dissolution, which, over a 50-year period, resulted in a 61 percent exposure of the wastes in the study of Harwell et al. (1982, PNL-2955) and 2.5 percent exposure in the task-force study (ONWI, 1981, ONWI-320[1]). Another significant difference is the existence of a sump. A relatively immobile sump, composed of insoluble material, forms at the bottom of a cavity, and exposed waste packages would likely fall into this region. The study of Harwell et al. (1982, PNL-2955) does not account for the presence of this sump and the ONWI study does.

None of the above studies considers the effectiveness of passive control measures, although such are required by the regulations. In fact, it is not clear at this point how quantatively to account for these measures. However, it is the consensus view of an ONWI task force (Human Interference Task Force, 1984, BMI/ONWI-537) that the passive control measures now being considered would be effective in reducing the risk of human intervention. Further, the NRC's final rule (*10 CFR 60.2*) does not require the analysis of human intrusion activities at the site, e.g., solution mining, if appropriate markers are used to mark the site and future generations are made aware of the hazards that exist. The DOE plans to use such markers and, therefore, does not plan to model solution mining.

Conclusion. Previous research suggests that various scenarios will not pose a significant hazard at the site. For other scenarios, involving both ground-water transport and direct access, that research is inconsistent at this point. However, for the latter group of scenarios, current research does indicate a strong sensitivity to the assumed source term. This research, especially for the case of solution mining, also appears to indicate that the consequence is reduced with increasing scenario refinement. In a general sense, this inverse relation of consequence to scenario refinement results from the fact that, in order to simplify the relatively complex phenomena at the repository and waste-package scales, authors have, in general, opted for high estimates of the source rate. The DOE will actively pursue realistic scenario quantification, both through its ongoing programs in site assessment and through engineering and shaft-seal performance assessments that are planned. Certainly, then, the available evidence does not support a finding that the site is not likely to qualify under Paragraph 960.4-2-8-1(a). Furthermore, the refined characterization of the critical scenarios, as typified above, will likely show that this site, in fact, qualifies for final nomination under 10 CFR Part 960, Appendix III.

6.4.2.7 Conclusions

Preliminary performance assessments have been completed for the Richton Dome site. These analyses are based on currently available codes, conceptual models, preliminary data (mostly generic to salt but not site specific) and interpretations. To allow for uncertainty, assumptions were generally made that tend to minimize package lifetime and maximize radionuclide releases. There is no evidence from these preliminary performance assessments that a repository at the site will not comply with the system criteria nor that the engineered subsystems would not be able to perform as required.

During the course of site characterization, key data and technology areas that will be emphasized are (1) brine migration, (2) solubility and other corrosion and waste form behavior characteristics using site-specific brines, (3) characterization of sources of water, and (4) in situ salt properties. Advances are needed in understanding, leading to more accurate modeling techniques as well as to the obvious necessity for site-specific data.

6.5 CHAPTER 6 REFERENCES

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State Parks and Forests, Miss. Code Ann. Secs. 55-3-1 et seq. and 49-19-1 et seq. (1982 & Supp. 1983).

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Appendix 6A

ESTIMATION OF THE EXTENT OF THE DISTURBED ZONE

This appendix presents only a preliminary and conservative description of the "disturbed zone" and in view of the limited thermal, mechanical, and hydrologic data existing on the host rock at the site, estimates of the disturbed zone are very likely to be revised following site characterization. The extent of the disturbed zone depends on the interaction of thermal, mechanical, and hydrologic effects. The disturbed zone is defined as, "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 the geologic repository" (DOE, 1984b, General Guidelines for Recommendation of Sites for Nuclear Waste Repositories, May 14). The definition is consistent with that given in 10 CFR Part 60; however, in order to be useful, the dimensions of the disturbed zone must be quantified.

What Constitutes a Significant Effect on Performance? The Guidelines specify that "significant effect" be evaluated. However, there is no definition of this phrase. The following discussion defines "significant effect." Since the disturbed zone is associated with the geologic setting performance measure, a significant effect must be defined relative to changes in ground-water flow or radionuclide retardation that jeopardize the ability of a particular site and associated repository design to satisfy the radionuclide release limit to the accessible environment. There are two ways, as follows, in which changes might jeopardize the ability to demonstrate compliance with radionuclide release limit standards:

1. Changes occur in ground-water flow characteristics or radionuclide retardation characteristics over a sufficient portion of the path to the accessible environment that the ability to meet the limit on release to the accessible environment is jeopardized.

2. Changes cause sufficient disruption over some limited portion of the path such that uncertainties in predicting long-term behavior are large enough to warrant discounting that part of the path in demonstrating compliance with the performance measures.

If condition (1) exists, it is likely that a site will be disqualified. In practical terms, the definition of a disturbed zone within an acceptable site is best defined by condition (2) above.

Potential Causes of Changes. The processes and phenomena that might affect long-term ground-water flow and radionuclide transport have been identified as follows:

Construction- and Operation-Related

- Mechanical effects on properties of rock
  - Induced fractures
  - Changes in existing fracture aperture
  - Crystal relaxation
  - Subsidence due to room closure

- Chemical effects on radionuclide transport
  - Introduction of oxygen, exhaust gases, etc.
  - Introduction of microbiologic organisms

Waste-Related

- Thermal-Mechanical
  - Thermal expansion of rock
    - changes in permeability
    - changes in porosity
    - uplift of stratigraphy
  - Creep closure of fractures
    - resultant rock flowage
    - closure of fractures
- Thermal-Hydrologic
  - Fluid density and viscosity changes
  - Brine migration
- Thermal-Chemical
  - Changes in natural chemical reaction rates, especially dehydration
- Radiation
  - Radiolysis of ground water
  - Crystal structure changes.

The definitions of the disturbed zone presented in the DOE Guidelines and in 10 CFR Part 60 explicitly mention changes resulting from underground facility construction and heat generated by the emplaced radioactive wastes. Therefore, this discussion includes operational effects (e.g., effects of ventilation), radiation effects, heat effects, and construction effects.

Physical Extent of Potential Changes. At this time, there are neither sufficient site-specific data nor sufficient definition of the site-specific repository design to precisely quantify the extent of the disturbed zone. However, estimates of the extent of various effects can be made from observations of salt behavior in mines at other locations and general knowledge of the change of salt properties with temperature and pressure from laboratory tests and calculations.

Construction- and Operation-Related Changes. Summaries of existing data related to flow or mechanical effects are presented below. The present data indicate that mechanical effects may be limited to no more than 15 meters (49 feet) from the excavations (rooms, tunnels, etc.). Field and laboratory measurements show that associated crystal relaxation tends to affect hydrologic properties of the host salt (e.g., permeability) only a short distance, typically less than 10 meters (33 feet), into the walls of the pillars. Specific evidence includes the following;

1. Field observations in the Cote Blanche Island salt mine (Golder, Brawner & Associates, Ltd., 1977, pp. 70-71) and Weeks Island mine (Acres American, Inc., 1977, p. 20) indicate that mechanical effects of excavation and resulting relaxation of the host rock cause fracturing and slabbing of the salt to a depth no greater than 1 to 2 meters (3 to 6 feet) into the pillars for rooms that averaged about 8 meters (25 feet) in height.

2. Additional field evidence is developed from the use of extensometers to measure displacements around a 5.5-meter (18-foot) shaft in salt in Saskatchewan at a depth of 939 meters (3,080 feet) (Barron and Toews, 1963, p. 122). These measurements indicated constant-volume creep at distances into the rock up to 2.1 meters (6.9 feet) and evidence of compaction of excavation-damaged rock in a surface "skin" about 1.2 meters (4 feet) thick. Barron and Toews (1963, p. 122) state, "The fact that creep proceeds without change of volume between the 4-foot and 10-foot points indicates that during the period of observation, there is no significant change in material properties of the salt between these two depths."

3. In situ permeability tests have been conducted in Grand Saline and Weeks Island mines (Aufricht and Howard, 1961; Acres American, Inc., 1977 and 1979). In these tests with packers set at varying depths, permeabilities decreased significantly with depth from the mined opening: at 0.6 to 1.5 meters (2 to 5 feet), permeabilities averaged about 0.3 millidarcy with measurements as high as 6 millidarcys; at 4.5 to 9 meters (14.8 to 29.5 feet), permeabilities ranged from 1.5 down to 0.001 millidarcys. These results are consistent with the slabbing observations and suggest a disturbed zone extending no more than a few meters (typically 1 to 2 meters [3 to 6 feet]).

4. The interpretation of these observations is aided by laboratory tests showing that salt permeability depends on confining stress. Results from several sources (Reynolds and Gloyna, 1960; Lai, 1971; Sutherland and Cave, 1978) show permeability reduces by 5 to 6 orders of magnitude as confining stress increases from zero to 70 megapascals (about 10,000 pounds per square inch). Results of such laboratory work were compiled by Isherwood (1981, NUREG/CR-0912).

5. Nair and Singh (1974) discuss a creep-rupture failure mechanism through which macroscopic fractures might be generated at a salt shaft or tunnel opening. Such ruptures might occur in a shallow zone (1 to 2 meters [3 to 6 feet]) around an opening, but propagation of the failed zone would be prevented by increased confining pressures at greater depth into the pillars (Kelsall et al., 1982, ONWI-405, p. 88).

6. Field measurements (BNI, 1983, Figure 9-1; 1985, WIPP-DOE-213, Figure 4-3) show that extensometer displacements end approximately 15 meters (49 feet) above the roof of a tunnel in a bedded salt. In this case, the DOE assumed an approximate zero strain boundary to correspond to the limits of mechanical disturbances.

7. Visual interpretations of the disturbed zone at domal salt sites (Golder Associates, Inc. 1985, Table 4-1) suggest maximum slabbing depths of 5 meters (16 feet), fracture depths of 6 meters (20 feet), spalling depths of 4.5 meters (15 feet), blast fracture depths of 0.6 meters (2 feet) and other excavation damage of 3 meters (10 feet).

8. Estimates of fracture depths of 15 meters (49 feet) by Kupfer (1980) are speculative and not substantiated by the generic data base developed by Golder Associates, Inc. (1985). In fact, telephone interviews documented by Golder Associates, Inc. (1985) state that Kupfer was not aware of any quantitative information on this subject. Kupfer (Golder Associates, Inc., 1985) believes that the old rule of thumb of fractures extending a half width of an opening is still valid. For the EA repository design, this gives a disturbed zone of 2.3 meters (12 feet) for CHLW and SF rooms and 2.9 meters (9.5 feet) for DHLW rooms.

9. Golder Associates, Inc. (1985, Section 4.2) discusses permeability tests from 1.5 to 8 meters (4.9 to 26 feet) and beyond 6 meters (20 feet) that suggest that fracturing has little effect at these depths because measured permeabilities represented lower limits of testing equipment and not actual (lower) permeabilities of the salt. Consequently, even with estimates of a somewhat larger zone of mechanical disturbance, permeability measurements still indicate that it is unlikely that fluids could leave the host salt.

In summary, the DOE has estimated a mechanically disturbed zone of 15 meters (49 feet) and recognizes that definition of the zone of mechanical disturbance depends on the following:

- Excavation method
- Extraction ratio
- Room size and shape
- Site-specific in situ stress field
- Site-specific geological structure
- Site-specific mechanical properties.

Therefore, only after site characterization and design selection can the DOE estimate more reliably the extent of the disturbed zone. In addition, the notion that "significant" mechanical disturbance extends to point of zero strain may prove to be too facile when the impact on radionuclide transport is considered. Mechanical disturbance may affect radionuclide disturbance for only much shorter distances according to field permeability tests reviewed by Golder Associates, Inc. (1985).

Chemical Effects on Transport. The introduction of oxygen, exhaust gases, microbiotic organisms, etc., onto mine surfaces during construction or operation may result in chemical changes that will influence radionuclide mobility. The potential effects of the introduction or removal of moisture from the mine by the ventilation system are also of interest. A small ground-water flux at a low velocity is projected under limiting studies (Sections 6.4.3.5 and 3.3.2.1; Gureghian et al., 1983, ONWI-494; D'Appolonia Consulting Engineers, Inc., 1980, ONWI-239). Radionuclide transport is expected to be controlled sufficiently by such low hydrologic fluxes, low ground-water velocities, and expected waste package performance (Section 6.4.2.3). Thus, effects of introduced chemicals on radionuclide transport are not expected to be significant.

Waste-Related Processes/Phenomena. The thermal-mechanical effects of interest include the following:

- Thermal expansion of the rocks resulting from heat generated by the emplaced waste
- Mechanical effects of this thermal expansion coupled with potential subsidence of the overlying strata (particularly aquitards between overlying aquifers and the salt strata)
- Effects in the immediate vicinity of the repository openings, including room closure, bedding-plane slip, fracture healing, backfill consolidation, and changes in the hydrologic properties of the host rock interbeds.

These can be summarized by two basic concerns: (1) the potential for fracturing aquitards from the thermal behavior of host formations, and (2) the changes in hydrologic properties in the immediate vicinity of repository openings due to thermal-mechanical processes.

Thermal-Mechanical Effects on Properties of the Rock. One thermal-mechanical effect that is to be considered for a potential repository site within a dome is the possibility of fracturing the caprock or dome flanks. Rigorous analyses of the effects of thermal-mechanical expansion or increased plasticity on the caprock and flanks of the dome have not been performed. A rigorous estimate of the potential for opening existing fractures or creating new fractures in the caprock or flank material because of thermal-mechanical expansion of the dome is difficult. The history that has been left by the dome's diapiric growth indicates that anhydrite deposition heals any fracturing.

Estimates of the dissolution rates provided by Murphy (1985, Table 4-1) range from as little as 1 centimeter (0.5 inch) to 5 centimeters (2.0 inches) per 1,000 years prior to 25 million years ago. Little or no dissolution has occurred during the past 25 million years and any that has occurred during this period is most likely the result of caprock fracturing due to arching of the underlying salt. It is anticipated that the impact of fracturing caused by thermal expansion of the salt would be less severe than the impact caused by arching of the salt.

Thermomechanical analysis performed by Loken et al. (1984) shows that the caprock will not experience any tensile stress due to thermal loading. However, if strength values for intact (not fractured) specimens of caprock as measured in the laboratory are reduced by 75 percent, a caprock shear strength ratio of 1.0 is indicated regarding fracture of caprock during the lifespan of the repository. The ratio implies that if intact caprock laboratory strengths are reduced by 75 percent, the analysis predicts an adequate balance of the stresses generated by the differential thermal expansion of the salt and caprock. Further, if the in situ strength of the caprock is less than 25 percent of the value measured in the laboratory, the existing caprock is likely more fractured than anticipated; therefore, because there is little, if any, evidence of recent dissolution, the stability of the dome is verified.

If unsaturated brine penetrates any fractures, a saturated brine equilibrium will eventually develop and inhibit dissolution. In addition, continuous circulation of unsaturated brine is very unlikely because the hydraulic gradient between aquifers in this area is upward.

Another thermal-mechanical effect of interest is the response of any fractures around excavations and the response of the backfill material to pressure and temperature. Various analyses and tests discussed below indicate that, with time, the hydraulic transmissivity of the backfilled openings and the zone of rock disturbed by the construction process are reduced by creep closure. These tests indicate that this process of reducing porosity and permeability is accelerated by heat and pressure.

Openings in salt at depth tend to close. For example, there are 10 years of observations reported on the Esterhazy Mine in Canada (Mraz, 1978), 20 years of measurements from Jefferson Island Mine in Louisiana (Wynn, 1965), and 5 years of data from Weeks Island Mine in Louisiana (Acres American, Inc., 1979). In all cases the openings tend to close with time, although the rate of closure is site dependent.

The process of fracture healing must be considered when determining the thermal-mechanical effects on the disturbed zone created by construction. Limited data available from laboratory testing indicate the degree and rate of healing that might be expected under repository conditions. Tests at Sandia (Costin and Wawersik, 1980, SAND80-0392) created a fracture in intact WIPP salt specimens. Then the specimens were pieced together and subjected to high temperatures (up to 100 C [212 F]) and pressures (up to 35 megapascals [about 5,000 pounds per square inch]) to heal the fracture. The specimens were then refractured to determine the degree of healing by measuring the stress required to refracture the specimen compared with that required for original fracturing. Results indicated that up to 80 percent of original strength was attained within a few days for all conditions except the lowest temperatures and pressures. Even at 22 C (72 F) and 10 megapascals (about 1,450 pounds per square inch), the strength of the fracture was on the order of 20 to 30 percent of the intact strength after a few days. Again, the specific data are not as important as is the indication that, as compaction of the backfill material proceeds, pressure will begin to increase. As resistance of the backfill increases, pressures will, in time, be attained that are sufficient at repository temperatures to begin healing any fractures in the in situ salt, thus reducing its porosity and permeability.

Based on the limited testing of fracture healing mentioned above, it is concluded that fractures in the salt adjacent to a bulkhead placed in an opening in salt should be closed, if not totally healed, within a period of tens of years following bulkhead construction. The joints formed in salt should also be healed within a similar period.

In summary, thermal-mechanical effects on the hydrologic properties of the rock in the vicinity of the repository openings only reduce the potential for flow through these openings with time.

Thermal-Hydrologic Effects. A main factor that can affect the extent of the disturbed zone is the distance over which waste-generated heat affects the movement of ground water from the repository through salt. There are two distinct phenomena discussed under this topic: the effect on ground-water flow caused by changes in water density and viscosity, and the potential for brine migration due to a thermal gradient.

Preliminary calculations using finite element modeling have been accomplished to quantify the effect of heat on ground-water flow through salt. In these preliminary calculations, the Palo Duro Basin was selected as an example potential repository site. Since domal salt tends to be purer and have even lower bulk permeability than bedded salt, and since the horizontal hydraulic gradient of interest in the case of domes is less than the vertical hydrologic gradients of interest for bedded sites, the results for the Palo Duro Basin should predict higher water velocities through the salt than would be expected for the Richton Dome.

It was assumed that a porous media (Darcian) flow model could be used to appropriately evaluate the rate of ground-water movement through salt. Under these assumptions, the pre-waste emplacement interstitial ground-water velocity in the Palo Duro salt sequence was predicted to be downward at about 2×10^{-5} meter (6.5×10^{-5} foot) per year for a hydraulic conductivity of 10^{-6} meter per day (0.0012 millidarcy) for the salt and downward at about 1×10^{-3} meter (3×10^{-3} foot) per year for a hydraulic conductivity of 10^{-4} meter per day (0.12 millidarcy).

With heat generation equivalent to that of the conceptual repository design (RRC-IWG, 1983, ONWI-483, Table 2-1, p. 8) superimposed on the evaporite formation, a time-dependent flow velocity was predicted in the salt between the Yates Formation and the Lower San Andres Unit 4 salt. However, the velocities remained small for all cases modeled. A summary of results is presented below:

Assumed Hydraulic Conductivity for Salt, m/day	Steady State Interstitial Velocity (Pre-Waste Emplacement)	Interstitial Velocity (Considering Waste-Induced Heat)
10^{-4} (0.12)	$\sim 1 \times 10^{-3}$ m/yr	3×10^{-2} m/yr at 100 yr 1.2×10^{-3} m/yr at 1,000 yr 1×10^{-3} m/yr at 10,000 yr
10^{-6} (0.0012)	$\sim 2 \times 10^{-5}$ m/yr	1.5×10^{-3} m/yr at 100 yr 4×10^{-4} m/yr at 1,000 yr 1×10^{-4} m/yr at 10,000 yr

From the above data, an estimate can be made of the distance traveled by water from the vicinity of the repository toward the accessible environment while flow is influenced by the waste-induced heat. This distance reflects the potential impact of waste-induced heat on radionuclide transport. Even at a high value of hydraulic conductivity for salt (10^{-4} meter per day [0.12 millidarcy]), the ground water is predicted to travel 10 meters (33 feet) or less from the repository in 1,000 years. In less than 10,000 years, the flow regime will have returned to near its steady-state condition.

For a hydraulic conductivity of 10^{-6} meter per day (0.0012 millidarcy) (still fairly high for salt), the simulation indicates a similar distance traveled (less than 10 meters [33 feet]) before steady-state conditions return. For this lower hydraulic conductivity, the predicted velocities are lower, but the period during which heat influences the flow is longer. These two factors tend to compensate for one another, resulting in a similar distance traveled, while flow is influenced by waste-induced heat. Therefore, it appears that the effects of waste-generated heat on ground-water flow through salt might affect repository performance (radionuclide transport) over distances of about 10 meters (33 feet).

Although the preliminary calculations are for bedded salt, the effect of heat on flow from the repository regime in the purer dome salt would very likely be less.

Brine migration due to the temperature gradient in the vicinity of the waste package affects the water content of the salt only a few meters into the salt (Section 6.4.2.3.2; RRC-IWG, 1983, ONWI-483, pp. 17-21). The initial water movement is toward the thermal source, not away from it.

Radiation Effects. Radiation affects host salt properties only in the immediate vicinity of the waste packages, on the order of 1 meter (3 feet) or less into the salt (RRC-IWG, 1983, ONWI-483, pp. 24-30).

Conclusion. Several processes and phenomena that could affect the rock surrounding the repository have been discussed. Results show the following estimates for disturbed zone size:

Disturbance	Range
Mechanical	Less than 15 meters (49 feet) (uncertain, depending on mining parameters; site-specific data required)
Chemical	Expected to be insignificant
Thermo-Mechanical	Disturbance tends to close openings and heal host rock fractures
Thermal-Hydrologic	About 10 meters (33 feet)
Radiation	<1 meter (3 feet)

On the basis of this discussion, the maximum range of the disturbed zone is estimated to be about 15 meters (49 feet). There is uncertainty in this estimate for mechanical disturbances since the extent of mechanical and hydrologic effects depends on site-specific data. Therefore, this estimate may be revised when site-specific data at the repository horizon become available.

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.

<u>Ease of characterization and modeling</u>. 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.

<u>Complexity of engineering measures</u>. 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 developed 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.

<u>Summary of comparative evaluation</u>

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.

Potential for foreseeable human activities that could affect containment and isolation. 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).

Capability for waste isolation. 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).

Major considerations

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.

Evaluation of the sites in terms of the major considerations

Remoteness. 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.

Extreme-weather phenomena. 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.

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 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 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

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 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.

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.

Protected State or regional resource areas, Native American resources, and cultural sites. 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 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.

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.

Potential impacts on direct and indirect employment and business sales. 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.

<u>Potential impacts on public agency revenues and expenditures</u>. 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.

<u>Major considerations</u>

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.

<u>Evaluation of the sites with respect to major considerations</u>

<u>Transportation safety</u>. 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 CONSIOERATION 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.					

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 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 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 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 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.					

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

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 <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 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.

<u>Expected impact of fault displacement at the repository site</u>. 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.

Summary of comparative evaluation

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

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.
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.
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.

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.
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.
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.

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.
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.
buffer zone	A portion of the site that surrounds the repository and is composed of an essentially undisturbed geologic and surficial environment.
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 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.
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 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.
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.
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.

cone penetrometer test	An in situ test that provides information necessary to calculate the load-bearing capabilities of a formation by using an instrument to measure the force required to thrust a cone downward into the soil.
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.
core hole	Any hole drilled for the purpose of obtaining cores.
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.
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.
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.
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.
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.
crowned roads	Roads which are slightly elevated at center to facilitate drainage.
cumulative impact	Projected impact of a proposed facility in combination with other existing and proposed facilities and actions.
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.
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.
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.
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.
diffraction (of sound)	The process by which the direction of a sound wave front is changed in direction by an obstacle or other nonhomogeneity in a medium.
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.
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.
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.

dome growth	A term used to describe the process of salt-dome development.
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.
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.
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.

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.
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.
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.
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 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.
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.
flat-jack test	Testing apparatus used for the determination of in situ stresses or rock-mass deformability.
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.
fluid inclusion	Brine inclusion; a small opening in a rock mass (salt) containing brine; also the brine included in such an opening. Some gases also may be present.
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.
friction hoist	A type of mine hoist in which the hoist drum supports a cable which passes over, but is not wound around the drum. The friction of the cable on the drum is sufficient to pull the cable and the supported weight. The cable extends down both sides of the drum into the shaft, so that both ends of the cable must be weighted, either by a cage or a counterweight.
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.

gassy mine — Underground operation in which the content of noxious or explosive gasses has been shown to exceed levels specified in 30 CFR Part 57 by the Mine Safety and Health Administration.

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.

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."

gouge — The clay or clayey material in a fault zone. Also crushed rock along a fault slip.

gneiss — A foliated rock formed by regional metamorphism, in which bands of granular materials alternate with bands of minerals with elongate prismatic habit.

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 acceleration	The rate of change of velocity of the ground produced by the motion of natural phenomenon (e.g., earthquakes) or man-made events (e.g., explosions and other testings).
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).

halokinesis — In salt tectonics, a general term for the study of the structure and mechanism of emplacement of salt domes and other salt-containing structures.

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-efficiency particulate air (HEPA) filter — A filter capable of removing at least 99.95 percent of particulate material as small as 0.3 micron from an air stream (0.3 micron is approximately the size of the particulate material in tobacco smoke).

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.
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.
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.
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.
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.
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.
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.
impulsive sound	Sound of short duration (less than 1 second).
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 placé (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).

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.

interstice
: An opening or space between rock materials or soil particles.

interstitial brine
: Brine distribution in very small openings throughout a salt mass.

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.
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.
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.
L_{eq}	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.
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."
migration	See "brine migration."
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."

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.
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.
nuclide	A species of atom with a specific mass, an atomic number, and a nuclear energy state; also referred to as an "isotope."
occupational dose	The radiation dose received by a person in a restricted area or in performing work duties involving exposure to radiation.
operational phase	The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning.
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.
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.
package	See "waste package."

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.
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.
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.
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.
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.
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 its 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.
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.
pyroclast	An individual particle ejected during a volcanic eruption.
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.

refraction (of sound) — The process of changing the direction of sound propagation by spatial variation in the speed of sound.

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."
rim syncline	In salt tectonics, a local depression that develops as a border around a salt dome, as the salt in the underlying strata is displaced toward the dome.
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.
sabkha	An environment of sedimentation, formed under arid to semiarid conditions on restricted coastal plains just above normal high-tide level. Sabkhas are characterized by evaporite salt and tidal-flood and wind-blown deposits.
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.
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.
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 x 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 x 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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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

ACFM	actual cubic feet per minute
ACHP	Advisory Council on Historic Preservation
ACR	area characterization report
Act	Nuclear Waste Policy Act of 1982
ADT	average daily traffic volume
A/E	architect-engineer
AEC	Atomic Energy Commission
ALARA	as low as (is) reasonably achievable
ANSI	American National Standards Institute
AQCR	air quality control region
ATMX	code of special railcar used in shipping defense wastes
AUM	animal-unit month
BAT	best available technology
BHA	bottom hole assembly
BLM	Bureau of Land Management (U.S. Department of the Interior)
BP	before present
BWIP	Basalt Waste Isolation Project
BWR	boiling-water reactor
C	Centigrade
C&C	consultation and cooperation
CEQ	Council on Environmental Quality (council which administers the National Environmental Policy Act)
CFR	Code of Federal Regulations
CHLW	commercial high-level waste

CH-TRU	contact-handled transuranic waste
COE	Corps of Engineers (U.S. Army)
COG	Council of Governments
CRRD	Conceptual Reference Repository Description
CRWM	Civilian Radioactive Waste Management (Program) (formerly NWB)
D&E	Design and Engineering
D&D	decontamination and decommissioning
DB	drill-and-blast (method of exploratory shaft construction)
dB	decibel
dBA	A-weighted decibels (sound pressure levels)
DBE	design basis earthquake or event
DBF	design basis flood
DBT	design basis tornado
DEIS	draft environmental impact statement
DHLW	defense high-level waste
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOE/NPO	U.S. Department of Energy, National Waste Terminal Storage Program Office (former)
DOE/SRPO	U.S. Department of Energy, Salt Repository Project Office (previously NPO)
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DST	drill stem test
EA	environmental assessment
ECR	environmental characterization report

EDB	engineering data borehole
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ES	exploratory shaft
ESF	exploratory shaft facility
F	Fahrenheit
FEIS	final environmental impact statement
FR	Federal Register
FRP	fuel reprocessing plant
FSAR	final safety analysis report
FWS	U.S. Fish and Wildlife Service
GD	Gibson Dome (borehole)
GEIS	generic environmental impact statement
gpm	gallons per minute
GROA	geologic repository operations area
GSA	General Services Administration
HAW	high-activity waste
HEPA	high-efficiency particulate air (filter)
HLW	high-level waste
HMTA	Hazardous Materials Transportation Act
hp	horsepower
HVAC	heating, ventilating, and air conditioning
IAEA	International Atomic Energy Agency
ICC	Interstate Commerce Commission

ICRP	International Commission on Radiological Protection
ILW	intermediate-level waste
L_{dn}	day-night weighted equivalent sound level measurement
L_{eq}	24-hour energy equivalent noise level measurement
LHD	large-hole drilling
LLW	low-level waste
MM	modified Mercalli (scale)
MPC	maximum permissible concentration
mrem	millirem
MRS	monitored retrievable storage
MSHA	Mine Safety and Health Administration
MSL	mean sea level
MTHM	metric tons of heavy metal
MTU	metric tons of uranium
NA	not applicable
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act of 1969
NIOSH	National Institute of Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission; National Research Council
NRHP	National Register of Historic Places

NSP	National Siting Plan
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act of 1982 (Public Law 97-425)
NWTS	National Waste Terminal Storage (Program) (former name; replaced by Civilian Radioactive Waste Management Program)
OCRWM	Office of Civilian Radioactive Waste Management
ONWI	Office of Nuclear Waste Isolation
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OWI	Office of Waste Isolation
PABX	private automatic branch exchange
PAC	potentially adverse condition
PL	Public Law
PMF	probable maximum flood
ppm	parts per million
PNL	Pacific Northwest Laboratory
PSD	prevention of significant deterioration (air quality standards)
PUREX	plutonium and uranium recovery through extraction
PWR	pressurized-water reactor
QA	quality assurance
QC	quality control
RAD	radiation absorbed dose
RCRA	Resource Conservation and Recovery Act of 1976
rem	roentgen equivalent in man

SARP	safety analysis report for packaging
SCFM	standard cubic foot per minute
SCP	site characterization plan
SCR	site characterization report
SEARS	Socioeconomic Assessment for Repository Siting (model)
SFPWR	spent fuel from pressurized boiler reactors
SHPO	state historic preservation offices
SJC-WCD	San Juan County Water Conservation District
SMSA	standard metropolitan statistical area
SRPO	Salt Repository Project Office
SRR	site recommendation report
Supply System	Washington Public Power Supply System
T&E	threatened and endangered
TDS	total dissolved solids
TEF	test and evaluation facility
TRU	transuranic (contaminated)
TSP	total suspended particulates
TWC	Texas Water Commission
UACR	Utah Air Conservation Regulations
UBC	Uniform Building Code
UCWRR	Upper Colorado Water Resource Region
UDOT	Utah Department of Transportation
USACE	U.S. Army Corps of Engineers
USBM	U.S. Bureau of Mines
USC	U.S. Code

USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of the Interior
USGS	U.S. Geological Survey
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
WISP	Waste Isolation Systems Panel
WNP	Washington Public Power Supply System Nuclear Project
WPPP	Waste Package Program Plan
WPPSS	Washington Public Power Supply System
WSA	Wilderness Study Area
WVHLW	West Valley high-level waste

Appendix A

TRANSPORTATION

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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.

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 <u>safeguarding</u> 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 <u>safety</u> 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.

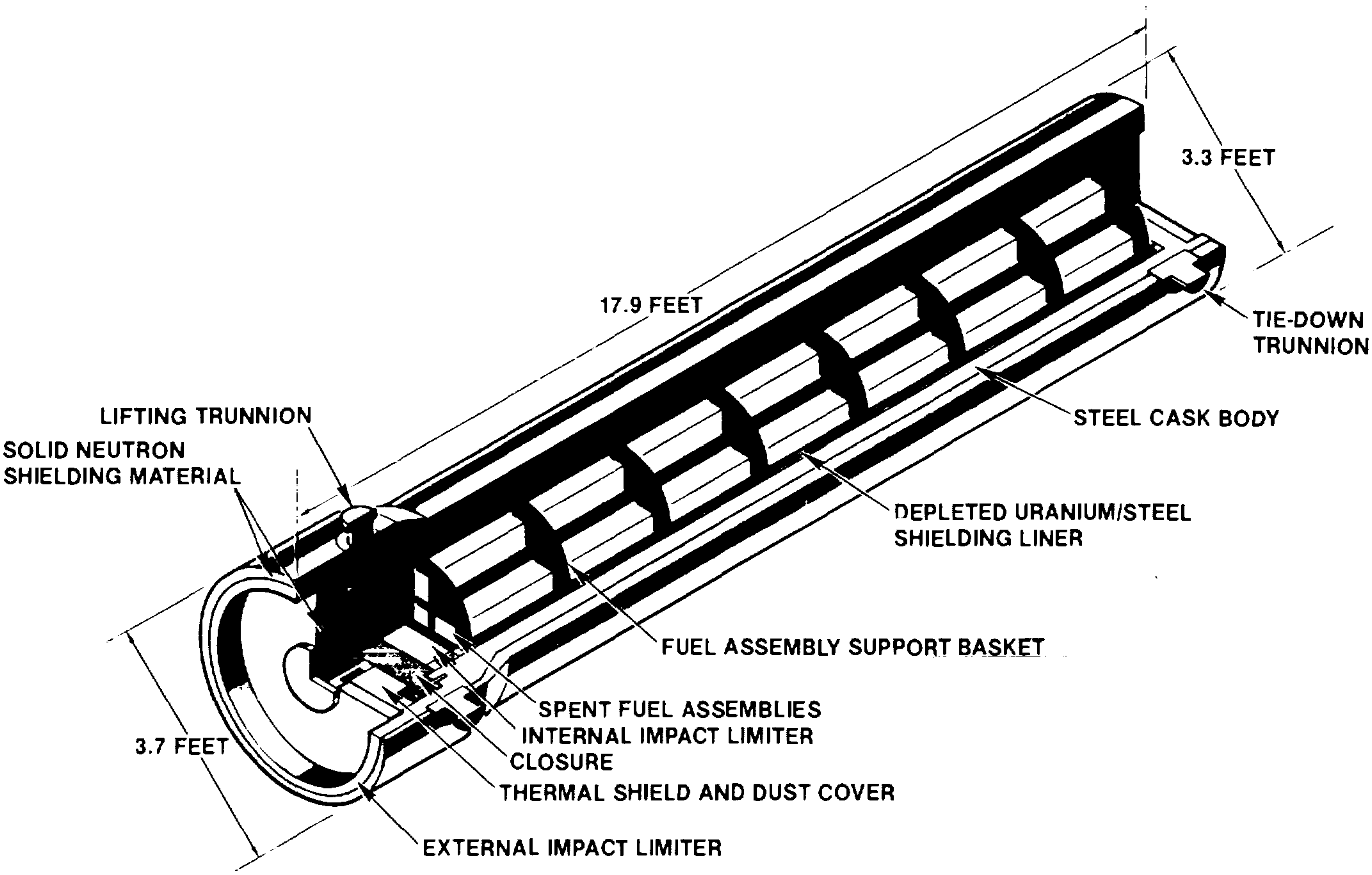

Figure A-1. Truck spent fuel cask.

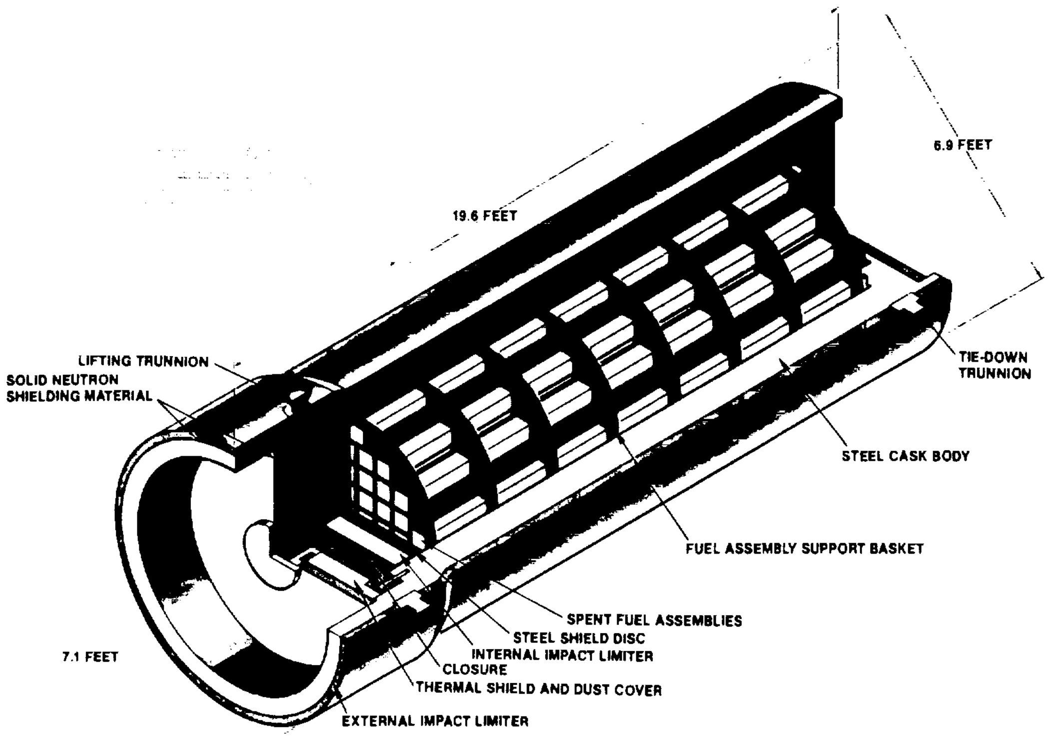

Figure A-2. Rail/barge spent fuel cask.

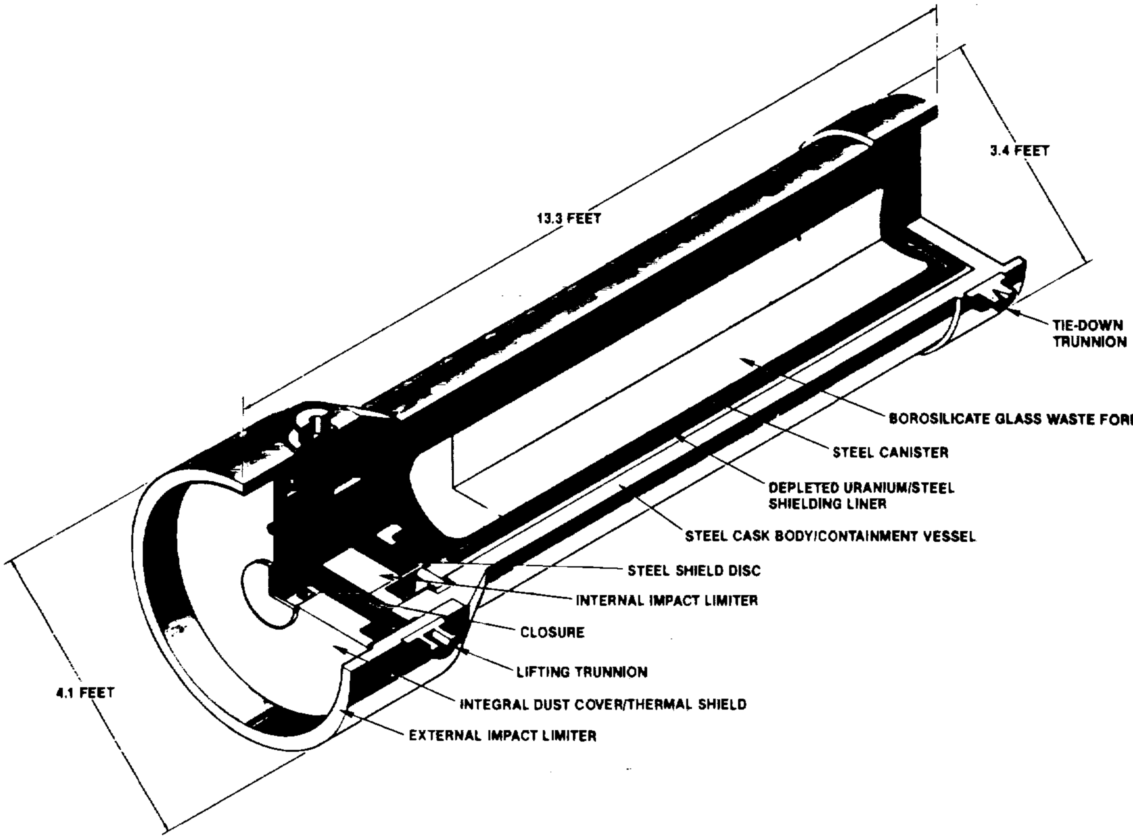

Figure A-3. DHLW truck cask.

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

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

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]								Water release in urban area[E]
	Urban area[C]				Rural area[D]				
	Inhalation	Plume gamma	Ground gamma	Total	Inhalation	Plume gamma	Ground gamma	Total	
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 x 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.

(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.

$§_1$= One of the population densities (6, 719, or 3,861 persons per square kilometer).

$§_2$= 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)

		High-level waste[a, b]			
Year	Spent fuel	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

Year	Spent fuel[a] (MTU)		Secondary waste products to repository		
	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.

Table A-8. Facility receipt rates for scenario involving only eastern reactors shipping to an MRS facility

Year	Spent fuel (MTU)			Secondary waste products to repository		
	Eastern reactors to MRS	Western reactors to repository	MRS 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]

Mode	Zone	Hazard group	Consolidated spent fuel[B]	Secondary waste		
			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	2890
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.

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.

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 – Richton	Salt – Deaf Smith	Salt – Davis Canyon	Tuff (Yucca Mt.)	Basalt (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.

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

	Salt						Tuff		Basalt	
	Richton		Deaf Smith		Davis Canyon		(Yucca Mt)		(Hanford)	
Waste source	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	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

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.

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	1B	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.

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.

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.

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.

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)

Mode and waste type	Repository Location: 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.

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

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.

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.

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.

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.

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

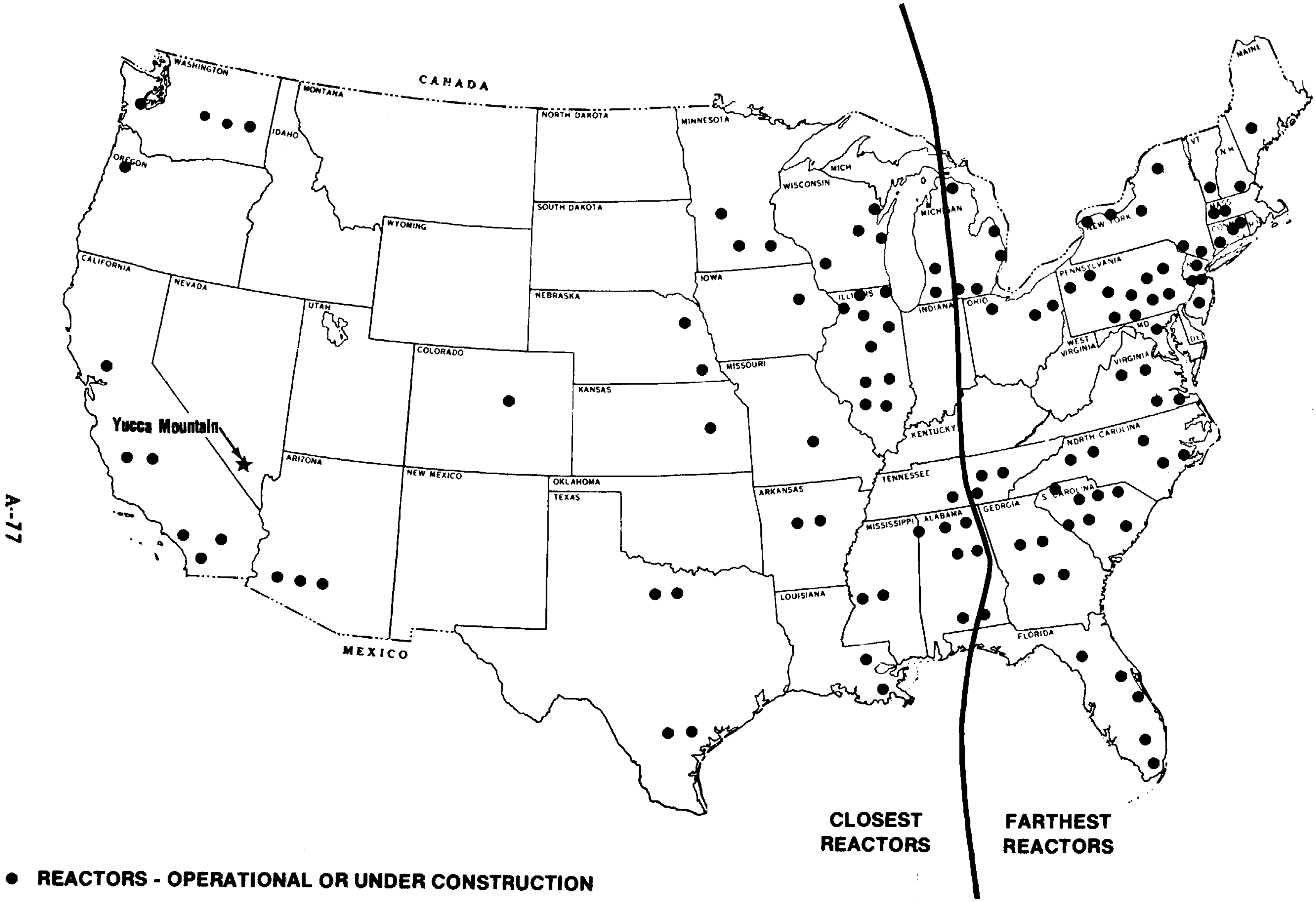

Figure A-5. Analysis of shipping from farthest and closest reactors to Yucca Mountain.

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 <u>regional</u> and <u>local</u> 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 <u>significant</u> transportation disruptions would not be <u>routine</u> 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" (Federal Register, 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.

- Explicit coverage of activities conducted under the Nuclear Waste Policy Act. 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.

- Application of ENO provisions to waste-management activities. 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.

- Source of funding. 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

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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

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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