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FINAL
ENVIRONMENTAL IMPACT STATEMENT

Waste Isolation Pilot Plant

Volume 2 of 2

October 1980

U.S. DEPARTMENT OF ENERGY
Assistant Secretary of Defense Programs

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ALTERNATIVE GEOLOGIC ENVIRONMENTS

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Appendix A

ALTERNATIVE GEOLOGIC ENVIRONMENTS

For the near future (10 to 15 years), the only method available for the permanent disposal of transuranic (TRU) and high-level wastes is emplacement in cavities mined in a geologic formation. Several types of geologic formations show promise as burial environments--salt, crystalline rock, argillaceous rock, and tuff. Which of these is to be used for a repository depends on when the choice among them is to be made; the longer one waits to make this decision, the greater the number of choices that are open. The time scales for these choices are summarized in Chapter 3 of this document.

As background material for the discussions in the main text of this document, this appendix briefly describes the properties of the four candidate types of rock. The U.S. Department of Energy (DOE) is investigating these four media for possible use with high-level waste as well as the TRU waste to be received at the WIPP. Reflecting the investigations, this appendix includes some discussion of properties like thermal conductivity that are critical to the design of repositories for high-level waste, but are not of major importance to the WIPP.

The current investigations of alternative geologic media are extensive, and this brief review is not intended to cover them thoroughly. A comprehensive review of the candidate geologic media appears in the draft generic environmental impact statement (GEIS) for the management of commercially generated radioactive waste (DOE, 1979). Another recent review has been made by the Interagency Review Group (IRG) on Nuclear Waste Management, whose reports (IRG, 1979; IRG Subgroup, 1978) contain recommendations about the choice of geologic media. References to other reviews and to detailed data appear in the GEIS and in the IRG reports.

After presenting background material that explains the bases for choosing a rock medium, this appendix reviews each of the four candidate media.

A.1 GENERAL BASIS FOR CHOOSING A ROCK MEDIUM

The selection of a specific medium depends on two major properties: geologic and hydrologic characteristics, which must resist forces that might expose the buried waste to the biosphere, and structural characteristics, which must permit the construction of a mined cavity without disturbing the geologic and hydrologic characteristics. A satisfactory rock medium must present little threat that its hydrologic and geologic characteristics could provide a mechanism or pathway by which the waste could return to the surface in harmful quantities.

The geologic characteristics are important because the purpose of a waste repository is to provide a place in which a solid material can be buried permanently. As long as the material remains solid, it has little chance of leaving its place of burial because it can do so only if some process opens the earth to the depth of the burial point or if the surface is removed to that depth. Therefore geologic formations that have been stable for long periods are sought for repository locations, on the assumption that the long-inactive disruptive forces in the earth there will remain inactive.

Material buried in solid form might return to the surface in another way: by being engulfed in a stream of water that dissolves the material and carries it to the surface. Because the forces that influence the flow of underground water are less catastrophic (and potentially more likely) than those that might uncover a deeply buried solid, the hydrologic characteristics of a medium may have greater influence on its selection than the geologic characteristics.

The structural characteristics of the rock are important because a repository must be designed, constructed, and operated in such a fashion that it will not upset the geologic and hydrologic characteristics. Because a repository is an engineered structure, its ability to isolate the waste will depend on the material in which it is constructed. Consequently, the selection of the geologic medium must facilitate the engineering design of a structure that will have a minimum probability of releasing its contents.

To be able to design the underground structure to minimize its impact on the hydraulic environment, the burial medium must be chosen with special attention to its mechanical, physical, and chemical properties. In repositories that contain heat-producing waste, the burial medium must be able to withstand the thermal stresses induced by that waste. Furthermore, establishing an effective design requires analytical models for the structure that take into account the properties of the geologic medium; without meeting this fundamental requirement, it would be extremely difficult to be confident that the design of the repository meets the fundamental requirements. The ability to conduct the engineering analysis depends strongly on a thorough knowledge of the properties of a proposed medium. For this reason, the preferred medium must have well-studied properties.

To decide in detail whether the properties of a geologic medium are satisfactory requires that several questions be answered, including the following:

- Will the subsurface structure be able to remain open and operable over the planned lifetime of the repository?
- Can the structure be used for waste disposal without adversely affecting the surrounding geologic and hydrologic environments?
- Can the structure be used without adversely affecting its own structural integrity?
- Will the structural material be adversely affected by heat, and will it react chemically with the waste?
- Will the surrounding geologic material react chemically with the waste?

By reviewing these questions along with others, it is possible to identify specifically the important properties of a geologic medium. Among the chemical properties, it is necessary to understand the solubility and chemical stability of the medium, its ability to resist chemical change during heating, and the corrosiveness of fluids it contains. Important mechanical properties include tensile and compressive strength and stress-strain relationships as expressed by elastic and bulk moduli. Important physical properties include thermal conductivity, thermal expansion, heat capacity, and decrepitation temperature. These properties are not known equally well for all the candidate media.

In addition to knowing these basic data, it is important to have a well-developed mathematical model for predicting the mechanical behavior of a repository in the chosen medium. This model must predict the stresses, deformations, and temperatures that the geologic medium will experience. It must model the mechanisms by which the structure or its surroundings can fail; it can then test the conditions (stress, temperature, etc.) under which failure could occur.

Each of the four sections that follow reviews a geologic medium in the context of this discussion. Table A-1 compares the three major geologic media according to a number of important properties.

A.2 SALT

When geologic media were first evaluated for the emplacement of radioactive waste, salt was judged to be the best choice for a number of reasons, including long-term geologic stability, spatial predictability, suitability for engineering analysis, thermal and mechanical properties, ease of repository construction, freedom from circulating groundwater, chemical stability, and the existence of extensive masses of uniform material. The original report of a committee established by the National Academy of Sciences-National Research Council (1957) recommended that salt be evaluated as a storage medium because it has excellent thermal and physical properties. The report pointed out that the existence of salt formations for several hundred million years demonstrates that they have been isolated from disturbing forces on the surface and from circulating groundwater; consequently, there is an extremely high probability that they will remain isolated in the future. Other desirable features of salt formations are their uniform consistency, simple geologic structure, and predictable stratigraphic character over large regions. Furthermore, the mechanical and physical properties of salt are known well enough to provide a good basis for the engineering analyses necessary for designing a repository.

Experiments to confirm the evaluation of salt as a suitable geologic medium began in 1965 under Project Salt Vault (Bradshaw and McClain, 1971), which operated for 2 years. Other experiments have been conducted over the past decade at the Asse experimental repository in the Federal Republic of Germany (Kuehn et al., 1976). The experiments have confirmed the basic understanding of the fundamental properties of salt and the engineering analysis required to design a repository in salt.

Project Salt Vault brought to the attention of repository designers the phenomenon of brine migration: small amounts of brine that occur in salt (usually less than 1% by weight) move toward emplaced heat sources. It has been asserted that accumulations of brine in salt can lower its mechanical strength. As long as the brine remains distributed, however, its impact on strength will be minimal. Migration phenomena and reduction in strength can be considered potential problems only when elevated temperatures with large

Table A-1. Comparison of Geologic Media

Property	Salt	Basalt or granite	Shale
BASIC PROPERTIES			
Plasticity	High	None	Variable
Solubility	High	Very low	Very low
Sorptive capacity	Low (depends on impurities)	Fair	High
Compressive strength	Moderate	High	Moderate
Thermal diffusivity	High	Low	Low
Thermal stability against chemical decomposition	High	High; potential dewatering of clay in basalt	High; potential dewatering of clay
IN-SITU PROPERTIES			
Porosity	0.5%, interstitial	1%, cracks	5-30%, cracks
Permeability	Essentially none	Decreases with depth	Very low
Water presence	Isolated from flowing groundwater	Present, open to flowing groundwater	Present, open to flowing groundwater
Corrosiveness of indigenous fluid	High	Low to moderate	Low to moderate
Tectonic stability	Very stable	Very stable areas can be found	Very stable areas can be found
Geologic structure	Relatively simple areas can be found	Fracture systems often complex	Like salt
Hydrology	Moderately difficult to characterize	Difficult to characterize	Difficult to characterize
PRACTICAL MATTERS			
Availability	Good	Good	Good
Need to use explosives	No	Yes	Possibly
Understanding of medium for repository use	Well studied	Not well studied	Not well studied
Waste rock	Reuse some; pile needs protection from erosion and runoff	Reuse some; pile probably does not need protection	Reuse some; pile needs protection, but less than salt
Mathematical modeling	Relatively simple; well developed	Relatively complex; not fully developed	Relatively complex; not fully developed

thermal gradients are present. The migration of brine toward heat sources is being investigated to determine whether it can increase the water content of the salt near hot waste and affect the strength of the salt there.

In a TRU-waste repository, reduced strength of salt due to the presence of brine is of minimal significance because little heat-producing waste will be emplaced there. For centuries underground mines have been built in salt; the stability of these mines has not been measurably affected by the presence of brine. The TRU waste in the repository will not provide significant heat-induced perturbing forces on the structure or its surroundings.

The intrinsic properties that make salt an attractive medium include uniformly low permeability, high thermal conductivity, abundance in thick masses, and plasticity that enables fractures to heal themselves at feasible repository depths. However, the high solubility of salt requires that extensive knowledge of regional and site hydrology be obtained before a repository site is selected; it will be necessary to develop an understanding about possible future groundwater flow at a chosen site.

The solubility of rock salt in water is two orders of magnitude greater than that of any other candidate medium. If man-made or natural events caused a breach in the repository, circulating groundwater could release the radionuclides in the waste, although the sorptive capacity of the geologic materials along the flow paths would retard the release of these nuclides. A thorough knowledge of these sorption properties is required for the particular rocks and the particular groundwaters at a repository. Generally, the sorptive capacity of salt is low and dependent on the impurities in salt.

Extensive salt mining in many locations around the United States and abroad has resulted in a well-developed salt-mining technology. One particular advantage associated with salt mining is that, after shaft construction, explosives are not needed. Electrically powered continuous-mining machines can construct the storage rooms; diesel-powered carriers haul the mined salt to branch-corridor conveyors, which are frequently extended to keep the hauling distances as short as possible.

Salt differs from basalt and shale in the potential environmental impacts of the waste rock from mining that has to be stored at the surface. The surface-storage pile would have to be designed to limit wind erosion and precipitation runoff in order to minimize potential environmental impacts during and after repository operation.

In summary, salt is the best understood of all candidate geologic media with respect to its possible use as a waste-repository medium, and it offers advantages in thermal properties and plasticity. It is found in many places in the United States (Figure A-1).

A.3 CRYSTALLINE ROCKS

Basalt, granite, and other crystalline igneous and metamorphic rocks have been proposed as geologic media for a repository; extensive deposits that have been stable for millions of years exist in the United States. The evaluation of these media is in an early stage of data collection, and an effort is under

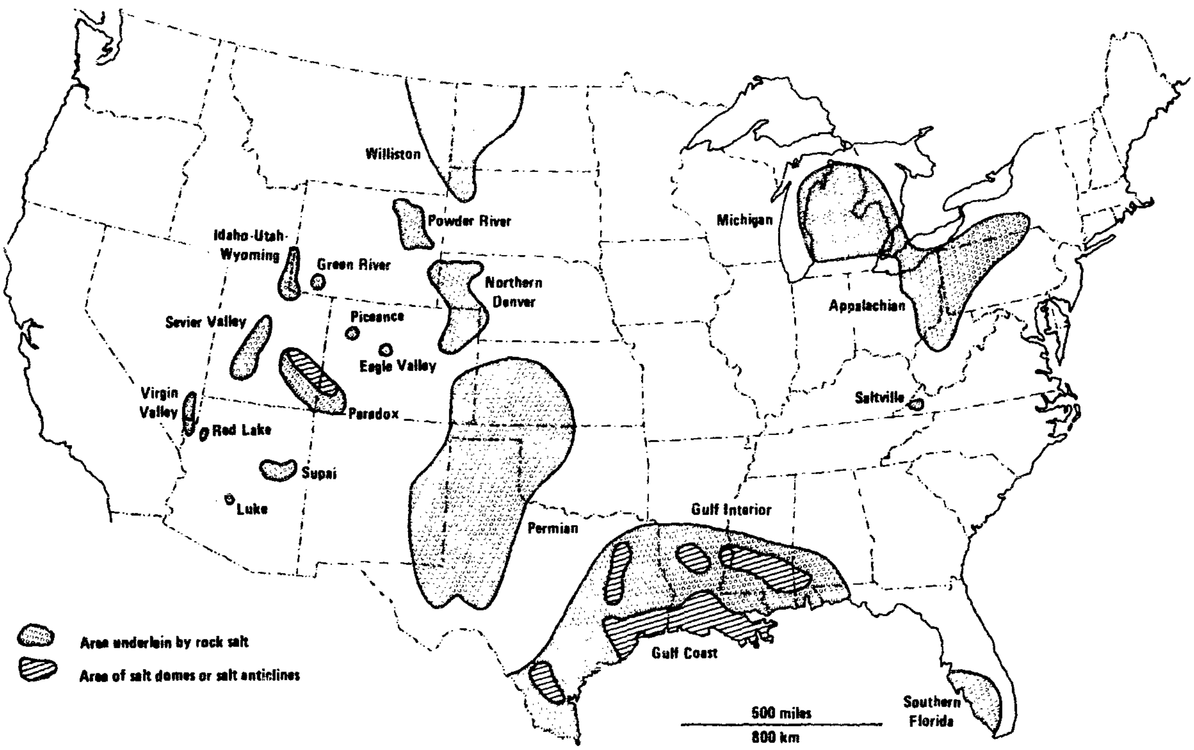

Figure A-1. Map of rock-salt deposits in the United States.

way to compile the information systematically. The basic mechanical properties (compressive strength, tensile strength, modulus of elasticity, etc.) of these rocks have been established through laboratory tests. The properties of the aggregate are, however, considered to be substantially different from those of the small samples of whole rock because crystalline rocks are fractured and cannot be reconstituted (unlike fractured salt, which will "weld" under lithostatic pressure). It is technically possible to build openings in crystalline rocks; still under development are analytical procedures that will completely evaluate the impact of thermal loads on mine structures in such rock or the surrounding rock formations.

Crystalline rocks do not dissipate heat as well as salt does; the thermal conductivities of crystalline rocks are about one-fourth that of salt. Each repository in crystalline rocks will be designed with heat loads adjusted to the thermal conductivity prevailing at the site. For some time heat transfer through crystalline rock has been considered a potential problem because the effects of cracks on thermal conductivity are not well known; heat dissipation in a medium with a random pattern of cracks is presently difficult to analyze. Experiments measuring heat conduction in granite are under way in Sweden and at the Nevada Test Site (NTS). The test at NTS showed that the cracks in NTS rocks affected the thermal conductivity by less than 10%. Tests conducted at both locations confirm that temperature distributions in hard rock can be calculated with a high level of accuracy.

Although large formations of salt, while soluble in water, are impervious to the flow of water, large formations of crystalline rocks are full of fractures that would provide convenient paths for water flow. In a backfilled, sealed repository built below the water table in crystalline rock, the cracks and void spaces may eventually fill with water. Because the cracks throughout the formation are mostly small, the ratio of water volume to rock volume is small. Nevertheless, a major drawback is that it is not yet possible to calculate the total flow and mass transport under the fracture-flow conditions. In addition, it is not yet possible to identify the effects that thermal loading will exert on the flow of water into or out of a sealed repository. Techniques for making these calculations are being developed.

Flow through a fractured medium will depend on the connectedness and size of the fractures. Their size is controlled to a large extent by the normal stresses acting across the fractures; since these stresses increase with depth, the permeability of crystalline rock usually decreases with depth. Although a model has not been established to accurately evaluate fracture flow, experience has shown that at depths of 1500 feet or more below the surface the fracture permeability is so low that it may not be a significant threat even when conservatively evaluated.

Because the water in crystalline rocks is more mobile than the water in salt, it may contribute to slow leaching of the radioactive nuclides from the waste. Although this condition might appear to be a problem, the magnitude of the problem is diminished because granite and basalt have sorptive properties that cause the radioactive elements in the water to be removed by chemical reactions with the rock. Furthermore, the typically low ionic strength of the water found in these formations reduces the possibility of adverse effects on these sorptive properties. Because of these favorable natural conditions, it appears that the corrosion of waste canisters stored in a crystalline-rock repository will be slow; the canister may maintain its integrity over many hundreds of years.

A major difference between repositories in crystalline rock and in salt will be in the methods of construction. While it will be possible in salt to use mining machines, crystalline rock will require drill-and-blast techniques whose impact on the integrity of a repository is still unknown. Such techniques might adversely affect the rock within a few meters around the mined openings. Since the rock beyond this affected volume will provide the required isolation, it is not clear that drill-and-blast construction will affect the long-term integrity of a repository. Experiments will be necessary to answer this question.

Major formations of granite and basalt exist in the United States; Figure A-2 shows their general locations. Reconnaissance studies have shown that the attractive granite formations include those in New England, the Rocky Mountain uplift, the Sierra Nevada Mountain Range, the Appalachian Mountains, and the Canadian Shield in northern Minnesota and Wisconsin. The basalt formations of interest are the Columbia Plateau Flood Basalts in Washington, Oregon, and Idaho. Because both the granite and the basalt formations are extensive, there is ample opportunity to find suitable sites. Field studies on the suitability of crystalline rocks are being conducted by the DOE at the Hanford Site, at the Nevada Test Site, and in Sweden. Sweden and Canada also have such programs.

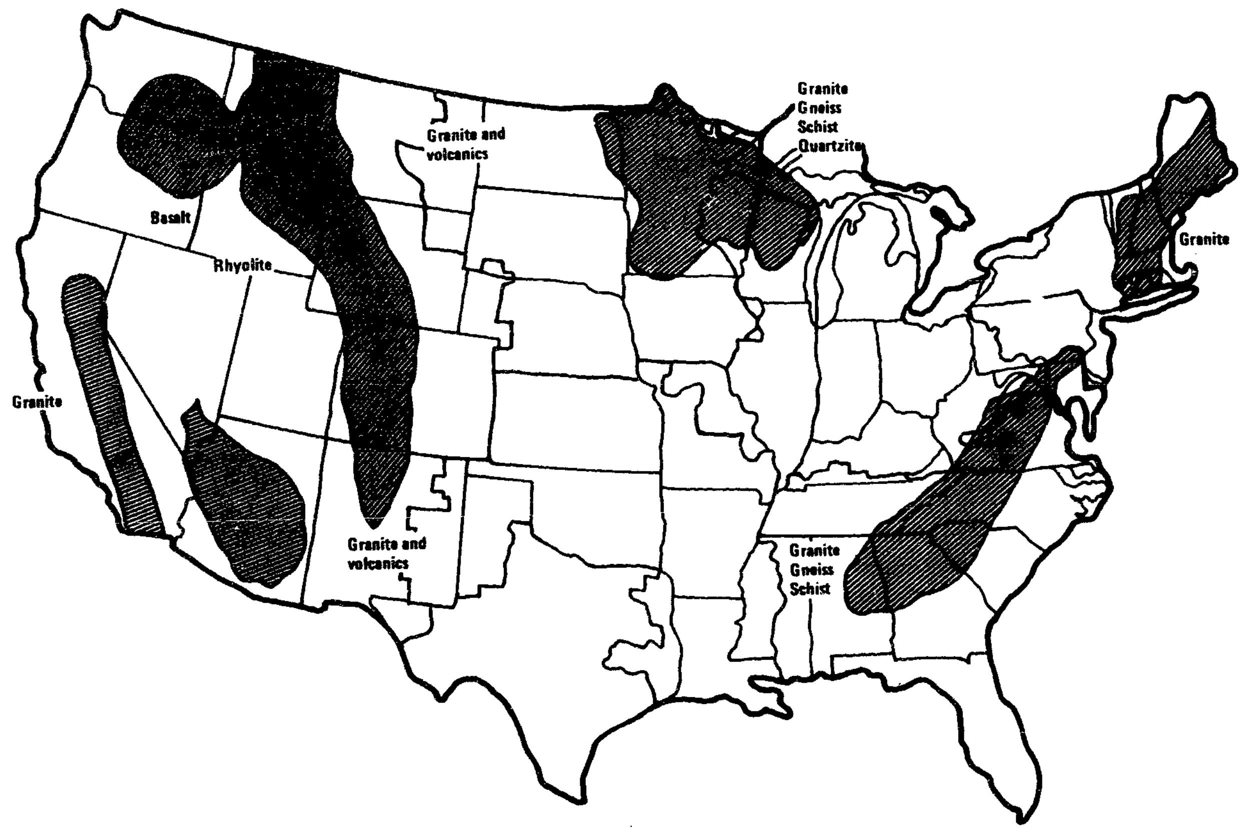

Figure A-2. Granite and basalt deposits in the United States.

A.4 ARGILLACEOUS ROCKS

Argillaceous rocks, especially shales, have also been proposed as geologic media for repositories. Argillaceous rocks vary widely in their characteristics: some shales are relatively plastic, with a high water content; others are relatively brittle, with a low water content. Because of the variation in their structure, these rocks vary widely in mechanical properties. Their strength in a direction perpendicular to the layers is often substantially different from their strength parallel to the layers. Shales exhibit good strength properties in compression but little or no strength under tensile load. Shales with a high water content may be highly plastic, deforming slowly under in-situ stresses; while good for closing cracks, this feature is poor for designing, constructing, and operating a mine that must remain open for 20 years. The anisotropy of shale and the possible variations in its properties make shale repositories difficult to model and analyze generically. Site-specific analyses and designs will be necessary for each proposed shale repository.

The ability of argillaceous rock to dissipate heat is comparable to that of crystalline rock. While facilitating uniform heat flow, the presence of substantial quantities of water in shale may set a relatively low upper limit on the temperature of the waste to avoid producing high-pressure gas through the conversion of water to steam. The design of a repository in shale will adjust the thermal output of the waste to avoid this possibility. Experiments with heaters have been conducted in two different types of shale. The results of tests in wet layered shale are consistent with the above picture. Tests in nonlayered low-water-content shale indicate heat-dissipation characteristics similar to those of granite and basalt. These tests confirm that temperature distributions in different types of shale can be calculated with an acceptable level of accuracy (Tyler et al., 1979).

Shale, a material of low in-situ permeability (Magara, 1971), is insoluble in water; it deforms under lithostatic loads, closing inherent joints. Because of these properties, water does not move easily through shale, even though shale may contain substantial quantities of formation water. Although heat could produce a major driving force to move the water, most of the waste to be received at a TRU-waste repository will not provide such a heat load.

Argillaceous rocks, like crystalline rocks, may provide an aqueous environment conducive to slow corrosive attack on the encapsulated waste. Water entrapped in shale is of intermediate ionic strength, which moderately inhibits corrosive action on canisters. After a canister has been penetrated, the dissolution of the waste inside would also be slow because of the intermediate-level ionic strength of the water. The presence of radionuclides in the water will be mitigated by two major factors: the slow rate of water movement through the tight shale formations and the strong sorptive capacity of the shale minerals, which reduces the concentration of radionuclides in the water through chemical reactions.

The methods for constructing a repository in shale will vary: the soft layered type of shale could be mined with machines, while the harder argillites might require drill-and-blasting techniques. A major concern about the construction and operation of a repository in shale is the possible occurrence of squeezing zones: thin layers of unusually soft, plastic material that could be squeezed by lithostatic forces into mined openings. A study of the Eleana argillite at the Nevada Test Site showed that a repository in this type of formation would require substantial expenditures for necessary structural supports underground because of the presence of squeezing zones (Fenix and Scisson, 1978; Yaner and Owen, 1978).

Large formations of argillaceous material are located in the United States; the largest is the Pierre Shale, in portions of North Dakota, South Dakota, Colorado, Montana, and Wyoming. Figure A-3 shows the location of this and other major argillaceous formations in the United States.

A.5 TUFF

Tuff is composed of material ejected from volcanoes; some of the best tuff formations are located in volcano calderas. It has only recently been considered for repositories; data on its suitability have been gathered for approximately 1 year. Figure A-4 shows regions in the United States where tuff

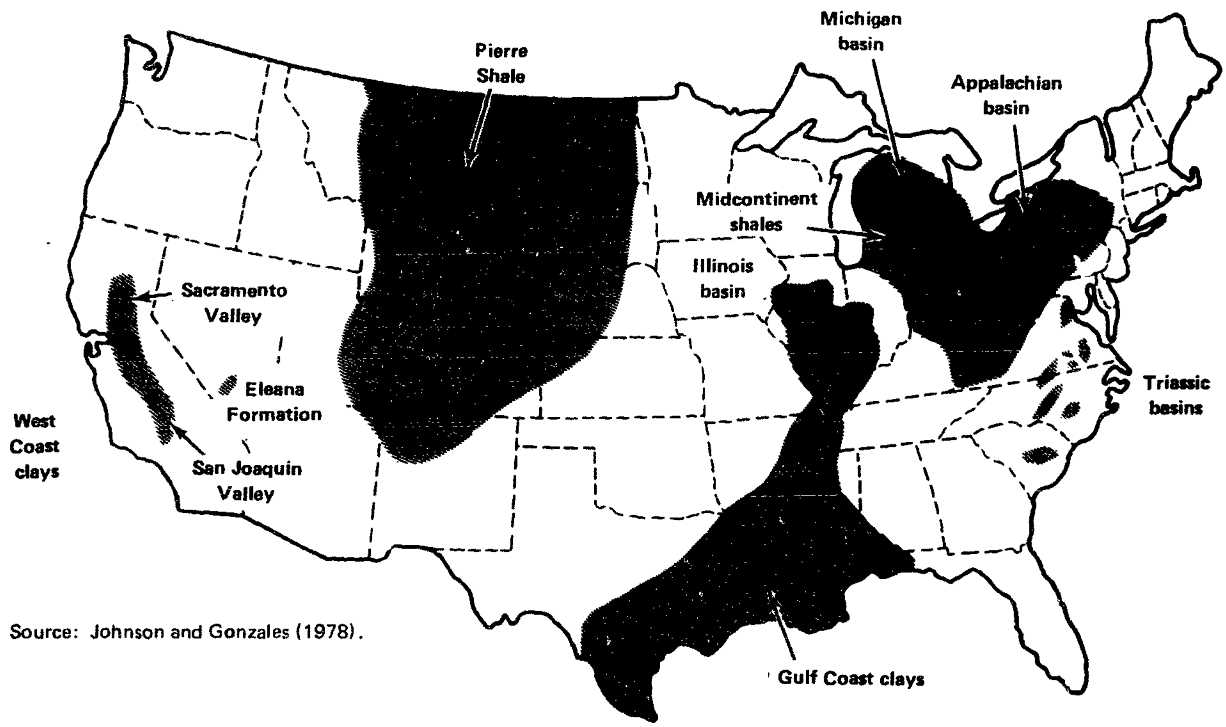

Figure A-3. Deposits of argillaceous rock in the United States.

deposits are found. None of these regions are in the eastern part of the country; material originally ejected from volcanoes there has metamorphosed and is not classified as tuff.

There are two types of tuff to consider. Welded tuff has low porosity, low permeability, high strength, good thermal stability, and moderate chemical sorptivity. Nonwelded tuff has high porosity, low permeability, high water content, low strength, good thermal stability when dry, unusual thermal expansion properties, and extremely high chemical sorptivity. The first investigations of these materials suggest that they are promising media for the geologic disposal of waste.

Because of the process by which tuffs are deposited, the welded tuff is usually surrounded by at least a partial envelope of nonwelded tuff. If a repository were built in such a formation, the welded tuff would provide high mechanical strength and thermal stability while the surrounding nonwelded tuff would provide strong sorption of radionuclides. This arrangement could be a nearly ideal set of multiple barriers under the proper mineralogical and hydrologic conditions. Because the arrangement is complex, the engineering design of a repository in tuff will be difficult; however, the benefits could be significant.

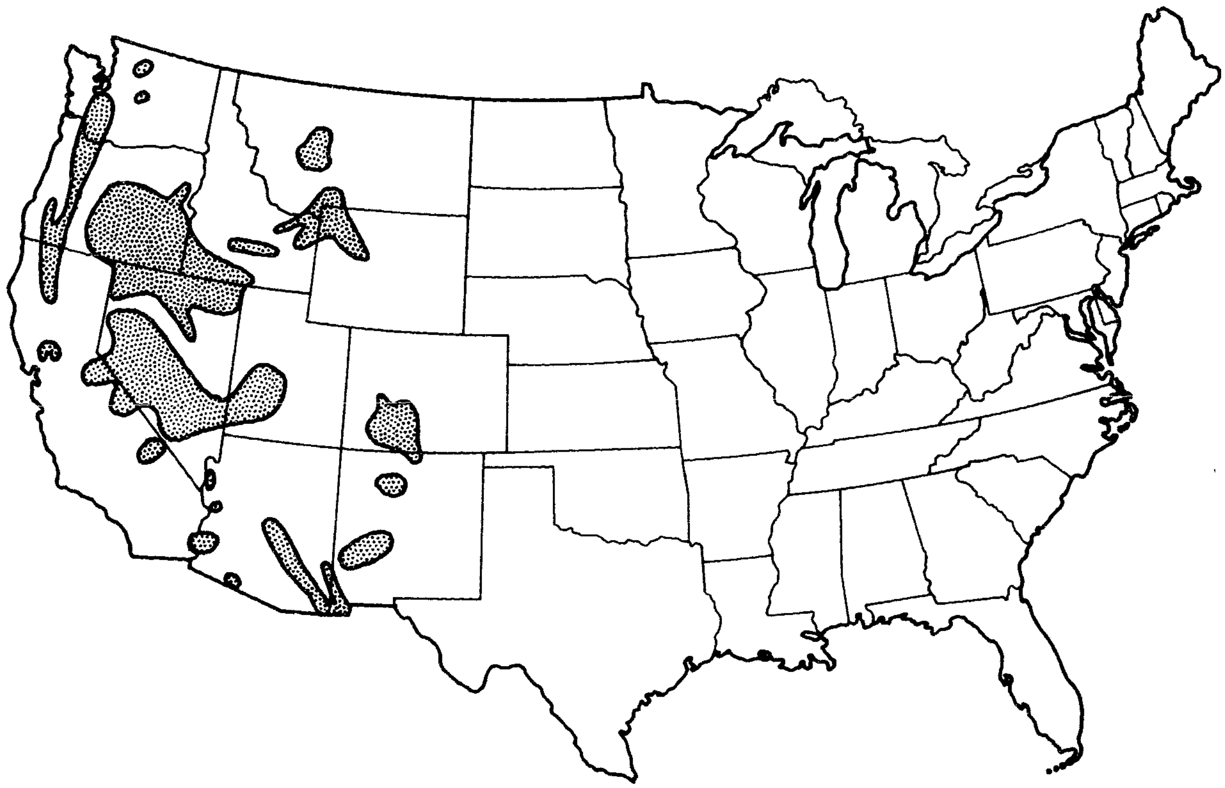

Figure A-4. Tuff deposits in the United States.

REFERENCES

Bradshaw, R. L., and W. C. McClain, 1971. Project Salt Vault: Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines, ORNL-4555, Oak Ridge National Laboratory, Oak Ridge, Tenn.

DOE (U.S. Department of Energy), 1979. Environmental Impact Statement: Management of Commercially Generated Radioactive Waste, DOE/EIS-0046-D, two volumes prepared by the Pacific Northwest Laboratory, Richland, Wash.

Fenix and Scisson, Inc., 1978. Minability Study of the Terminal Waste Storage Program--Eleana Investigation, NVO-0038-15, prepared for the U.S. Department of Energy.

IRG (Interagency Review Group), 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-29442, U.S. Department of Energy, Washington, D.C.

IRG Subgroup (Interagency Review Group), 1978. Alternative Technology Strategies for the Isolation of Nuclear Waste (draft), TID-28818, U.S. Department of Energy, Washington, D.C.

Johnson, K. S., and S. Gonzales, 1978. Salt Deposits in the United States and Regional Geologic Characteristics Important for Storage of Radioactive Waste, Y/OWI/SUB-7414/1, Office of Waste Isolation, Union Carbide Corporation, Oak Ridge, Tenn.

Kuehn, K., et al., 1976. "Recent Results and Developments on the Disposal of Radioactive Waste in the Asse Salt Mine," IAEA/NEA International Symposium on Management of Radioactive Wastes from the Nuclear Fuel Cycle.

Magara, K., 1971. "Permeability Considerations in Generation of Abnormal Pressures," Journal of the Society of Petroleum Engineers, Vol. 11, pp. 236-242.

National Academy of Sciences-National Research Council, 1957. The Disposal of Radioactive Waste on Land, A Report of the Committee on Waste Disposal, Division of Earth Sciences, Publication 519.

Tyler, L. D., J. F. Cuderman, J. L. Krumhausl, and A. R. Lappin, 1979. "Near-Surface Heater Experiments in Argillaceous Rocks," in Proceedings OECD/NEA Meeting on in situ Heating Experiments in Geologic Formations, September 12-15, 1978.

Yaner, P. I., and G. N. Owen, 1978. Nevada Test Site Terminal Waste Storage Program Subtask 1.3: Facility Hardening Studies: Design Cost Scoping Studies, JAB-99-123, prepared for the U.S. Department of Energy by John Blume and Associates.

Appendix B

THE NATIONAL WASTE TERMINAL STORAGE PROGRAM AND ALTERNATIVE GEOLOGIC REGIONS

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CONTENTS (continued)

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Appendix B

THE NATIONAL WASTE TERMINAL STORAGE PROGRAM AND ALTERNATIVE GEOLOGIC REGIONS

The National Waste Terminal Storage (NWTS) program of the U.S. Department of Energy (DOE, 1979) is directed at the development of facilities for the emplacement and disposal of high-level and transuranic (TRU) waste within deep geologic formations in order to provide safe, long-term isolation of the waste from human activities and from the environment. The program contains several elements:

1. Geologic studies to identify suitable geologic media and potential sites in various geographic regions.

2. Analysis of the behavior of radioactive waste in candidate geologic structures.

3. Engineering and design of operating repositories and associated specialized equipment.

4. Development of packaging and storage methods for unreprocessed spent fuel.

This appendix discusses the nature and status of the first program element listed above.

B.1 REGIONAL STUDIES

Site-evaluation activities include geologic investigations and supporting studies of the surface environment. These start on a broad national scale and subsequently narrow to candidate regions and then to investigations of areas within regions, finally resulting in work at specific sites. The confirmation of a potential repository site requires a detailed study of the geologic, hydrologic, environmental, and socioeconomic characteristics of the site. For a site to be acceptable, it must be established, in the framework of licensing regulations, that no credible circumstances would be encountered that would result in releases of radionuclides from the emplaced waste to the biosphere in quantities that would constitute a hazard to the public.

Geologic media being studied include salt domes, bedded salt, granite, shale, and basalt. These are found in many parts of the United States. Other materials, such as tuff and carbonate rocks, may also meet the requirements for a candidate host rock.

Most investigations of geologic disposal to date have centered on salt formations, and the primary emphasis of the NWTS program remains on salt domes and bedded-salt formations. Regional studies have been completed on the Permian basin of the Central United States, the Salina region (comprised of the Michigan and Appalachian basins) in the northeast, the Paradox basin of Utah, and the salt domes inland from the Gulf of Mexico. In addition, because they are DOE sites already committed to nuclear purposes, the Hanford Site in south-central Washington and the Nevada Test Site are being examined to determine whether suitable sites exist among the rocks they contain. The status of the site-selection studies is summarized in Section B.3. Sections B.4 through B.8 describe the regional studies and the work at the Hanford Site.

B.2 SAFETY STUDIES

A systematic evaluation of the safety and reliability of geologic disposal of radioactive waste is required in order to insure the viability of specific designs at specific sites being considered for repositories. In the NWTS program this evaluation is almost entirely in terms of the disposal of commercial high-level waste. These studies contain the following elements:

1. Models for analyzing disruptive events, both natural and man-induced.

2. Thermal analysis models.

3. Studies of interactions between the emplaced waste and the surrounding rock and groundwater.

4. Waste-migration models.

5. Borehole-plugging studies.

6. Systems analysis for linking all those effects together.

A basic program containing these elements, the Waste Isolation Safety Assessment Program (WISAP), is in progress. This program is independent of that used for the safety analysis reported in Chapter 9 of this document; one of its tasks, therefore, is to make analyses that parallel the Chapter 9 analyses. The principal purpose of the WISAP, however, is to aid in the site-selection and site-characterization activities of the NWTS program and eventually to enter into the environmental assessments required by the National Environmental Policy Act of 1969 for whatever sites are on the final list of alternative candidate sites.

B.3 STATUS OF SITE-SELECTION STUDIES

The earliest dates for the qualification of sites are as follows:

Geologic medium and location	Date
Bedded salt (other than Los Medanos)	1985
Dome salt (Gulf interior region)	1983
Basalt (Hanford)	1984
Nevada Test Site	1985
Other hard-rock sites	1985

B.3.1 Gulf Interior Salt Domes

The Gulf interior salt-dome region contains several hundred domes scattered across northeastern Texas, northern Louisiana, and central Mississippi. Picking a site in this region amounts to picking a particular dome, as they are discrete entities. At this point the main criteria are size, depth to top, and the nature of previous disturbances. Attention has been narrowed to eight domes, three each in Texas and Mississippi and two in Louisiana. Hydrologic characteristics, on the other hand, can be and are being studied regionally.

Most of the early knowledge of these domes has been obtained from the study and analysis of information from U.S. Geological Survey and state files and of drill-hole, seismic, and other geophysical data purchased from commercial interests. Indirect geophysical methods, such as aerial photogrammetry and infrared remote sensing, have also been used.

Early field evaluations resulted in the elimination of the Palestine Dome (Texas) in October 1979. Studies of the remaining seven domes are continuing. They include hydrologic studies of the three sedimentary basins in which the domes occur as well as dome-specific geologic and hydrologic studies. The understanding of dome locations is being further refined by gravity surveys, high-resolution seismic reflection and refraction surveys, and borehole evaluations. All of the seven domes being investigated are considered to be tectonically stable; no capable faults are known to exist in their vicinity. In late 1980, two or three domes will be recommended for further examination in the "location" study phase of the site-exploration process.

Salt domes appear to be viable alternatives to bedded-salt sites. Several European countries are considering salt domes seriously, and the Federal Republic of Germany has operated an experimental repository in a salt-flow structure for 13 years.

B.3.2 Hanford Basalt

The Columbia Plateau basalts cover a vast region of central Washington, northern Oregon, and western Idaho; much of it might in principle be of interest for waste disposal. For the practical reason that the Hanford Site in the State of Washington is already Federal land administered by the DOE for nuclear purposes, the detailed investigation of these basalts has centered on those of the Pasco basin, in which Hanford lies.

Geologic study of the area was begun more than a decade ago. Studies in the present context started in 1976; since then much mapping and geophysical work has been done, and 16 new holes have been drilled for cores, logging, and hydrologic tests.

The basic geologic structure consists of a series of lava flows separated by porous, water-bearing beds. There has been essentially no mineral exploration in these basalts, and there is little prospect for it. This, plus the extensiveness of the flows, implies that if any part of the structure proves satisfactory for waste disposal, there will probably be a great deal of choice in site selection.

The use of basalt can rely but little on experience and analysis made for salt. Therefore high on the program is the measurement of the physical, thermal, and chemical properties of the basalt, both alone and in the presence of groundwater. A Near-Surface Test Facility is being built in the northeastern portion of the Hanford Site for in-situ testing, especially with electrical heaters.

B.3.3 Nevada Test Site

The Nevada Test Site (NTS) is a large site, about 40 by 60 miles in size. It lies in the Basin and Range physiographic province and at the northern edge of the Mohave Desert ecosystem. Elevations range from 3000 to 7000 feet, and the climate and biological features vary greatly with elevation.

The primary mission of the NTS is the underground testing of nuclear weapons. Indeed, it is the only test site for this purpose now available to the United States. Because of the presence of residual fission products and transuranic nuclides on the surface and under the ground, the NTS is committed for the indefinite future to retention and care by the U.S. Government.

The NTS contains a variety of geologic environments that might be considered for waste disposal. However, potential interference with or by nuclear testing restricts areas that might be considered to those in the southwestern portion of the Site. Four such areas are under consideration; two are granite areas, one is shale, and one is tuff.

All four areas have been investigated by surface geologic mapping and geophysics, and two by drilling. Drilling into one of the granite areas was discouraging: the granite was encountered much deeper than aeromagnetic surveys had implied. The other area drilled was in tuff, and it continues to look promising.

At present only the Yucca Mountain location is being explored. This location is underlain by approximately 6000 feet of interbedded welded to nonwelded tuffs. An ideal geologic setting for a repository in tuff is a thermally conductive, mechanically strong, welded tuff enveloped by a low-permeability, highly sorptive, nonwelded zeolitized tuff. Field mapping, core drilling, and geophysical surveying are in progress to assess the extent to which these conditions exist at Yucca Mountain. A 6000-foot core and hydrologic test hole is being drilled into the study area; the results will be correlated with data from a 2500-foot hole drilled earlier. The water-bearing properties of inferred fracture zones in the Yucca Mountain area will be evaluated by hydrologic testing and geophysical surveys.

The NTS is in seismic risk zone 2, near zone 3. The Basin and Range province is well known to be seismically active. It is therefore necessary to find a block of material that has suitable properties and is sufficiently distant from active faults. Closely related is the question of volcanism; 12 to 13 miles southwest of the NTS there is evidence of volcanic activity as recently as 280,000 to 300,000 years ago.

The hydrologic characteristics of the NTS and its environs are well studied in the areas used or affected by nuclear testing but not in the southwestern area being considered for waste disposal.

B.3.4 Paradox Basin

Regional geology is still being studied in the Paradox basin in southeastern Utah and southwestern Colorado. In addition, three holes have been drilled in a structure called the Salt Valley anticline, one of the salt diapirs of the basin. The deepest of the three was continuously cored to a depth of about 4000 feet. Several types of geophysical logs have been run in these holes, and open-hole injection, pumping, and swabbing hydrologic tests have been conducted. The most recent activity has been vertical seismic profiling, in which a seismic source in one hole is detected in another hole.

In the near future, at least two deep holes, one in the Gibson dome area and one in the Oil Ridge area, will be cored, logged, and extensively tested. Preliminary results indicate that bedded-salt layers of sufficient volume are present at suitable depths in the Utah portions of the Paradox basin. The area is being investigated for historical evidence of earthquakes, especially in the basin itself. Studies of potential resource conflict and groundwater-flow systems are also in progress.

B.3.5 Permian Basin

Permian basin studies have concentrated on the Texas Panhandle. There is essentially no Federal land in the area, and access for drilling and other direct field work is difficult. Nevertheless a great deal of information is available from geophysical measurements and holes drilled by oil companies, and there have been a few holes drilled and logged by the NWTS program on the east edge of the Palo Duro basin.

B.3.6 Salina Region

The Salina bedded-salt region includes parts of Michigan, Ohio, Pennsylvania, New York, West Virginia, and Ontario. Regional studies for the New York and Ohio portions of the Salina basin have identified areas that appear to be geologically favorable to justify more detailed investigations. The Michigan portion of the Salina basin has not been studied in similar detail, but it is known that Michigan has salt beds of sufficient thickness and extent at suitable depths to meet general specifications for waste repositories. No field investigations have been carried out by the DOE in the Salina basin. Some field work in support of repository siting has been conducted in New York and Pennsylvania by the U.S. Geological Survey. Much additional information is needed before a potential repository site can be identified in the Salina basin. At present, no part of the basin has been investigated enough for a judgment of its acceptability as a repository site.

B.4 PERMIAN REGION*

B.4.1 Geology

The Permian region is located in portions of Texas, New Mexico, Oklahoma, Colorado, and Kansas, the entire region encompassing approximately 189,000 square miles (Figure B-1). The land surface consists predominantly of flat plains and tablelands, but some hilly and low mountainous areas exist east of the Midland basin in Texas and along the Wichita Mountains uplift in Oklahoma. Elevations range from 1500 to 2000 feet above the mean sea level in the eastern portion of the region to 5000 feet above the mean sea level in the west.

The Permian region has been tilted, warped, eroded, and invaded by at least one major sea since Permian time (280 to 220 million years ago). Rocks that predate the Permian period show local faulting and complex folding, but the Permian and younger strata are virtually free of deformation and in most areas have a dip of less than 0.5 degree. Most of the modern structures are probably of shallow origin and do not appear to reflect recurrent movement along Paleozoic or older structures.

The Permian region had a complex tectonic history during the Precambrian and Paleozoic Eras, culminating in the Wichita, Ouachita, and Arbuckle periods of mountain building, all of which occurred during the Pennsylvanian period (approximately 310 to 280 million years ago). It was in this tectonic framework that the region developed. A second period of mountain building, referred to as the Laramide orogeny, resulted in the uplifting of the Rocky Mountains just to the west of the Permian region about 65 million years ago, but this affected the region very little. In summary, the Pennsylvanian period of basin formation and crustal uplift is the only major tectonic activity that has affected the Permian region since Precambrian time, approximately 1 billion years ago. Structural readjustments since the Pennsylvanian have had little effect on the post-Permian rock units, including the extensive salt sequences.

The entire Permian region lies within seismic risk zone 1, which indicates that ground rupture should not be anticipated in the region. Recorded seismic activity is low compared with that of most other parts of the United States. Earthquakes with modified Mercalli intensities of V to VII are scattered sparsely over the region. Of the region underlain by salt, the only part that has undergone significant activity is the area on the flanks of the Amarillo uplift and along its west-northwesterly continuation across the Bravo dome and the Dalhart basin.

The Permian region has long been one of the major oil- and gas-producing regions of the United States. The hydrocarbon reservoirs of eastern New Mexico and west Texas range from Ordovician to Permian in age. Limestones deposited during Permian and Pennsylvanian time served as stratigraphic traps for hydrocarbons and have been the major producing strata in the Silurian, Devonian, and Ordovician systems. Future exploration is anticipated to the

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*Data from Environmental Characterization of Bedded Salt Formation and Overlying Areas of the Permian Basin (NUS, 1979a).

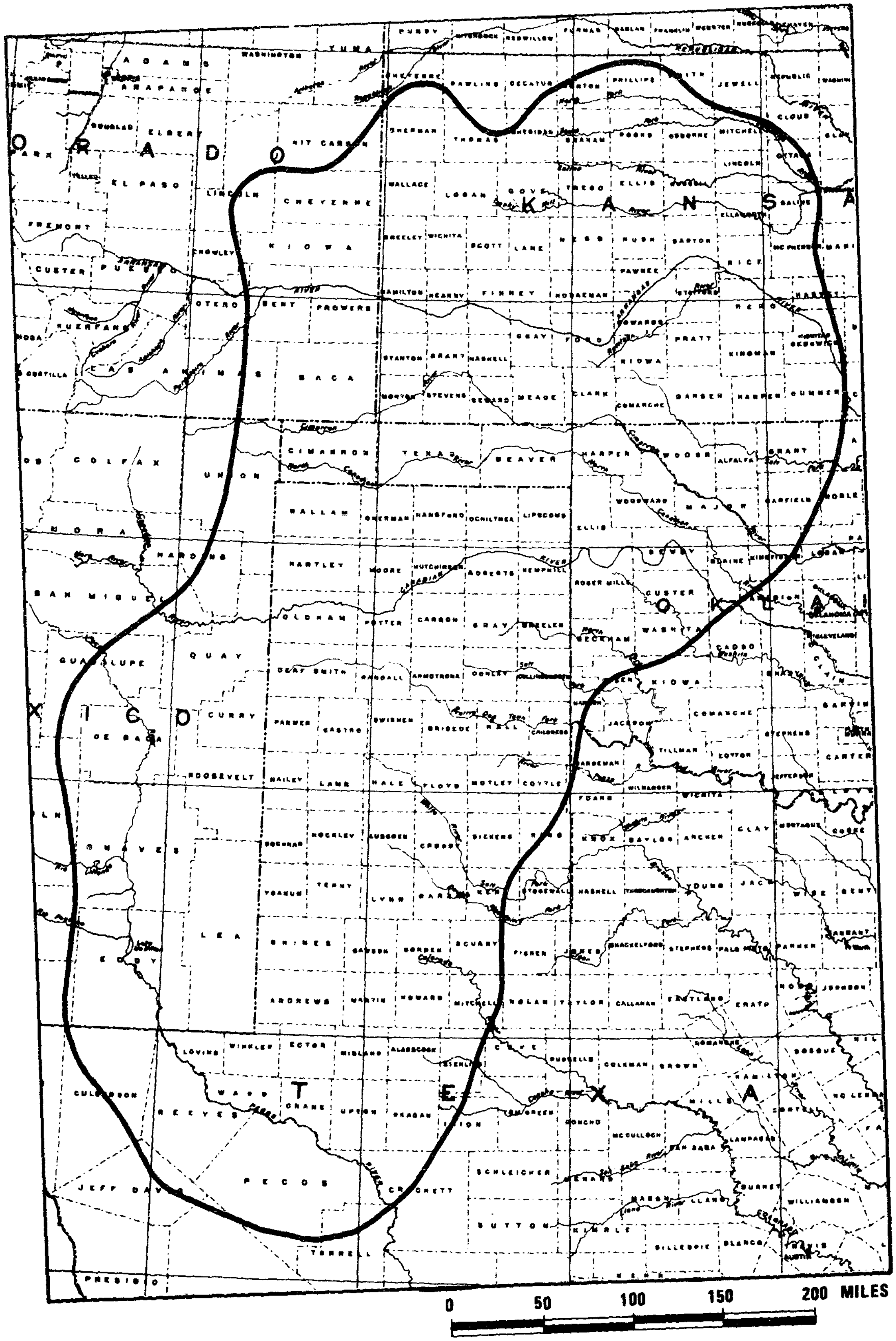

Figure B-1. The Permian bedded-salt basin.

north of the presently producing fields in southeastern New Mexico. In relation to the Upper Permian salt-bearing formations, most of the drilling for development and exploration will be at depths greater than those of the salt formations.

Major natural gas fields are present in western Oklahoma and the Texas Panhandle. There is some oil production in the area but far less than that of natural gas. The hydrocarbon-production zones in western Oklahoma and the Texas Panhandle are mainly lower Permian and Pennsylvanian strata. Most of the successful wildcat wells have found production horizons in Pennsylvanian and Mississippian strata, but deeper drilling is finding producing zones at depths of 25,000 feet in Silurian and Devonian systems. The principal oil-producing stratum is Pennsylvanian in age. Oil is also produced along the south side of the Palo Duro basin, along the crest of the Matador arch. Production is small from these basins. In addition to oil and gas, helium is produced at three localities, and carbon dioxide is produced from Permian rocks. On the basis of current leasing and drilling activity, it is anticipated that there will be exploration and development efforts for hydrocarbon zones below the Permian salt formations in western Oklahoma and the Texas Panhandle.

The southeastern Colorado portion of the Permian region supports oil and gas production that is small in comparison with that of the other producing provinces in the region. Principal hydrocarbon-production zones for this area are Pennsylvanian and Mississippian strata. Future drilling activity in southeastern Colorado will be in Pennsylvanian and Mississippian strata, which are stratigraphically below the Permian salt formations.

Major natural gas occurrences extend northward from western Oklahoma and the Texas Panhandle into Kansas. Hydrocarbon-production zones for the Kansas portion of the Permian region are in Cretaceous, Permian, Pennsylvanian, Mississippian, and Ordovician strata. It is expected that future drilling efforts for Paleozoic strata will continue at a high rate in southwestern Kansas. Helium is also produced in the Kansas portion of the region.

Lignite deposits occur in north-central Kansas, although production from this area is sparse. Lignite has also been mined from limited seams in Cimarron County, Oklahoma, for domestic heating purposes.

Uranium resources are scattered in small deposits across the south-central portion of the Permian region in eastern New Mexico, the Texas Panhandle, and western Oklahoma. A few local deposits are also present in the southeastern Colorado portion of the region. Production has been small because of the limited size of the deposits.

There are no known metal occurrences within the Permian region, though iron and titanium are found near its periphery in Kiowa County, Oklahoma.

The production of various nonmetals has been, and continues to be, one of the major industries in the Permian region. The nonmetallic mineral industry in the region includes construction materials (e.g., stone, sand and gravel, volcanic ash, and scoria). These nonmetals are extracted from depths of usually less than a few hundred feet, and thus extraction would not interact with the salt deposits under consideration. Evaporite (e.g., potash and anhydrite) deposits are also located extensively over much of the region.

B.4.2 Hydrology

The Permian region has a semiarid climate characterized by low rainfall and runoff, high evaporation, and frequent strong winds. The rivers in the region generally rise on the eastern slopes of the Rocky Mountains and flow southeastward across nearly flat plains, which slope eastward at 5 to 15 feet per mile. Rainfall and runoff increase and evaporation decreases to the east. The mean annual precipitation varies from less than 16 inches in the western part to about 30 inches in the eastern part. The mean annual runoff varies from less than 0.2 to about 4 inches from west to east. The quality of many streams in the region is poor because of natural contamination (salt, sulfates, silt) and man-made sources (oil-field brine, feedlot drainage, irrigation runoff, municipal and industrial discharges). In many areas, river water is unsuitable for most municipal, industrial, and agricultural water-supply purposes. Although major floods occur infrequently, localized flooding may occur as a result of intense local precipitation. In most areas, such floods are characterized by rapidly rising and falling peak discharges and high water velocities. Flooding is controlled or mitigated by reservoirs and flood-control dams on many streams in the region. Reservoirs are also used for minimum flow maintenance.

The largest single user of water in the region is agriculture (about 87% of the total consumption). Domestic uses, manufacturing, and steam-electricity generation account for most of the remaining water consumption.

Because of the limited availability and variable quality of surface water, groundwater has become the dominant water resource in the region. Sixty-three percent of the water withdrawn in the region comes from groundwater. Aquifer types include stream-valley alluvium; terrace alluvium; carbonate and gypsum; sand and sandstone; and undifferentiated sandstone, carbonate rock, shale, and basalt. The Ogallala aquifer is a terrace-alluvium aquifer extending from southwest Texas across parts of New Mexico and Colorado, and western Colorado, Oklahoma, and Kansas. It is the most important source of water in the region and is one of the most intensively developed in the United States. The zone of saturation ranges from a few feet to more than 250 feet, and the depth to water ranges from less than 50 to more than 300 feet. The yields of wells range up to 1500 gallons per minute (gpm), depending largely on the saturated thickness. The water is generally of good quality but can be hard locally. Virtually all of the withdrawal in the heavily pumped areas comes from storage (i.e., the water is being mined).

Alluvium and terrace deposits represent deposits of the major streams formed during the period of dissection of the High Plains and consist largely of reworked material derived from the Ogallala Formation. The alluvium and terrace deposits are nearly continuous along the major streams, although there are gaps along some of the streams where alluvial deposits are thin or absent. The zone of saturation ranges from 0 to 150 feet, and well yields range from less than 100 to 3500 gpm. The water ranges from fresh to highly saline.

The Edwards-Trinity (Plateau) aquifer is a sand and sandstone aquifer at the southern boundary of the Permian region. It consists of massively bedded limestone interbedded with shale. Although the yields of wells in most places average about 250 gpm, they can exceed 3000 gpm in places where the secondary permeability of the limestone is well developed. Water in the aquifer is generally fresh, although the concentrations of total dissolved solids can reach about 3500 mg/l.

The Rush Springs and Gerber-Wellington aquifers in Oklahoma and the Roswell artesian aquifer in New Mexico lie primarily outside the Permian region but do provide an important water resource to the portions of the region that they include.

B.4.3 Climate

The Permian region is in the Southern Plains and Lowlands climatic zone. In general, climatic changes are gradual across the zone because there are no significant climatic barriers. Differences in climatic conditions within this zone are controlled primarily by latitude, general air mass and other storm movements, elevation, and distance to sources of moisture.

The climate is predominantly continental, with cold winters and warm to hot summers. The western portion of the region has a dry climate because of the blocking effect of the mountains to the west. The modifying effect of the Gulf of Mexico results in a warm, humid, and rainy climate for the eastern portion of the region. The northern portions of the region are frequently affected by cold polar and arctic air masses during the winter and less frequently during the summer. Wind and precipitation patterns indicate a relatively high erosion potential.

Fundamental changes in the climate of the region have occurred over the last million years (the Pleistocene Epoch). During this period there have been four ice ages, the most recent of which ended about 10,000 years ago. Although glaciers did not extend to the Permian region, the climate was probably cooler, wetter, and stormier than at present. Flooding was probably more frequent. The current epoch (Holocene) is considered to be interglacial, and there are indications that a long-term global cooling trend is under way at present.

In the Permian region the 24-hour maximum rainfall with a 100-year recurrence interval ranges from 5 inches in the northwestern portion to 8 inches in the eastern portion. These values are typical for the contiguous United States. The frequency of tornadoes is noticeably greater in the central, northern, and eastern portions of the region. (Texas, Oklahoma, and Kansas are within an area of the United States that is associated with frequent occurrences of tornadoes.) Similarly, most of the northern and central portions of the region experience 100-year maximum winds with speeds of more than 90 mph, which is relatively high in comparison with typical values in the United States. Restrictive-dispersion conditions (inversions) are relatively infrequent in the region compared with the rest of the contiguous United States. The occurrence of restrictive-dispersion episodes increases from east to west across the region.

Air-quality statutes and regulations restrict development in areas that are not attaining the national ambient air-quality standards (unless certain offset criteria are satisfied) or where emissions would result in violations of the standards or would exceed increments established by the Clean Air Act Amendments of 1977. Data indicate that the national ambient air-quality secondary standards for particulates are being exceeded throughout the western half of the region and in some eastern areas. Furthermore, the particulate concentrations in the area between Amarillo and Midland, Texas, exceed the national primary ambient air-quality standards for particulates.

B.4.4 Background Radiation

Background radiation is ubiquitous, resulting from cosmic, terrestrial, and fallout sources. The limited data available for the Permian region reveal no anomalous areas.

B.4.5 Demographic, Socioeconomic, and Land-Use Systems

The Permian region is sparsely populated. Only three urban areas in the region support a population of more than 100,000 inhabitants: Wichita, Kansas (approximately 300,000), Lubbock, Texas (approximately 150,000), and Amarillo, Texas (less than 130,000). Odessa and Midland, Texas, have populations of just over 80,000 and 60,000, respectively. The largest urban area within 75 miles of the region is Oklahoma City, Oklahoma (approximately 580,000).

Total earnings for the Permian region in 1970 amounted to approximately 11 billion dollars; by the year 2000, earnings will be approximately 27 billion dollars. The dominant land use is agriculture. The livestock industry yields more earnings than all the field crops combined. Earnings from agriculture, forestry, and fisheries accounted for about 14% of all earnings; manufacturing accounted for approximately 13%. Mining and other extractive industries accounted for approximately 5% of the total earnings. Approximately 68% of the earnings was produced by retail and wholesale trade, government, and institutions. This percentage is expected to increase, whereas the percentages for agriculture and mining are expected to decrease in the coming decades.

Sensitive or conflicting commitments of land areas larger than 10,000 acres include 142,200 acres of Indian lands (trust areas) in Oklahoma. Also within the region are 2 national parks (93,720 acres), 5 national forests (639,321 acres), 3 wildlife refuges (64,606 acres), 11 recreation areas on Bureau of Reclamation projects (1,143,921 acres), 1 military installation (33,848 acres), and other military areas (primarily restricted air spaces), totaling 23,850,624 acres. The area committed to these activities is approximately 22.86% of the Permian region. The bulk of the land is range, agricultural, and open land, with some areas preempted for urban and residential development and for transportation networks.

The Permian region is traversed by a network of highways and rail lines. The highway system is the dominant mode of transportation throughout the region. Railroad trackage has been developed most intensively around major rail hubs within or near the northeastern portion of the region.

B.4.6 Terrestrial Ecosystems

The Permian region covers some 189,000 square miles and includes a variety of soil, topographic, and land-use patterns. About 98% of the region is classified as range or pasture (58%) or cropland (40%).

Most of the natural vegetation in the region is classified as grassland and shrubsteppe (97%), but forests (3%) are scattered along the major river drainages in Kansas, Oklahoma, and eastern Colorado and in the low mountains in the western portion of the region. Forests are not commercially valuable in the region because of their limited distribution. Nevertheless, they provide important wildlife habitats. Wetlands are scarce. However, six typical wetland areas are identified, one of which (the Great Salt Plains in Oklahoma) has been proposed for Registered National Landmark status. The region contains seven national wildlife refuges in wetland areas. The Society of American Foresters has identified two natural areas in Kansas that are set aside for scientific, educational, or recreational purposes. The Nature Conservancy has designated at least three natural areas in the Oklahoma portion of the region. Twenty-four plant species that are proposed for the Federal list of endangered species occur within the region.

Regional wildlife includes some 85 species of mammals, at least 350 species of birds, and more than 100 species of amphibians and reptiles. Forestland, shrubland, and openland species are well represented. Important wildlife includes game species, furbearers, and one species on the Federal list of endangered species, the black-footed ferret. At least 35 game birds and 26 game mammals are found in the region, and hunting and trapping are important. The white-tailed deer, mule deer, and pronghorn are important big-game animals. Cottontail, jackrabbit, and fox squirrel are important small-game mammals. Nonmigratory game birds include the turkey, ring-necked pheasant, lesser prairie chicken, bobwhite, and scaled quail; migratory game birds include waterfowl and the mourning dove. Birds on the Federal list of endangered species include the brown pelican, Mexican duck, bald eagle, peregrine falcon, whooping crane, and Eskimo curlew.

The major land uses in the Permian region are cropland and range and pasture. The major cropland areas are in Kansas and Texas; Texas and New Mexico have the largest amounts of range and pasture land. Important crops include winter wheat, sorghum, and cotton. Cattle, sheep, hogs, and milk cows are important livestock.

B.4.7 Aquatic Ecosystems

A large portion of the Permian region is semiarid, with intermittent streams as the only aquatic habitat. These streams, when flowing, are generally high in mineral content from natural sources (salt springs, brine seeps, or gypsum overburden) and from human activities (petroleum and natural gas production or irrigation return flows). As a result, the most suitable (often the only available) aquatic habitats are near the peripheral portions of the region.

In the northern portion of the region, streams of the Smoky Hill River system, which drain ultimately to the Missouri River, are turbid and moderately salty. During low-flow periods in summer months, particularly in the upper reaches, these streams become ephemeral. Near the northeastern boundary of the region and below the confluence of the Saline and Solomon Rivers, the Smoky Hill River system maintains adequate flow and supports a marginal recreational fishery for catfish and carp. The Topeka shiner, a threatened fish in Kansas, has been recorded from the Smoky Hill and Saline Rivers within the Permian region.

Rivers of the north-central Permian region, including the Arkansas, Cimarron, Canadian, and Red Rivers, have poor water quality as a result of natural and man-induced pollution. These streams (with a possible exception of the Arkansas River) have their origin in semiarid regions and frequently exhibit no flow or subsurface flow conditions. Consequently, suitable habitats for aquatic organisms are mainly outside or near the eastern periphery of the region. A few locally endangered or threatened species may occur in the north-central portion of the region but are expected primarily in the headwater areas of Colorado and New Mexico or near the eastern boundary of the region, where the streams become larger and flow continuously.

Much of the central Permian region, although within the watersheds of the Brazos and Colorado Rivers, consists of playa lakes and dry creeks and is essentially noncontributing. Aquatic habitats are therefore few in number and, when present, are generally not suitable for fish and aquatic invertebrates because of the naturally high salt content of surface waters. A few tributaries (e.g., the Concho River of the Colorado River system, which is essentially spring-fed) maintain flows and water quality that support exploitable fish populations. Such streams are generally near the eastern boundary of the region.

In the south and southwest portions of the Permian region, the Pecos River, although polluted from natural brines and irrigation return flows, supports a diverse fish fauna in tributaries to the main-stem river. Many of the species and subspecies of this region (particularly the several species of desert pupfish and gambusia) have been isolated by natural barriers and are restricted to specific habitats (often a single tributary or spring). Because of their highly restricted distributions and dependence on unique habitats for survival as a species or subspecies, many of these fishes are considered to be endangered.

B.5 SALINA REGION*

B.5.1 Geology

The Salina region includes portions of New York, Pennsylvania, Ohio, Michigan, West Virginia, and Ontario (Figure B-2). The entire region encompasses approximately 80,000 square miles of land area in the United States.

About half of the Salina region is in the Great Lakes section of the Central Lowland physiographic province. The lakes and terrain features, such

*Data from Environmental Characterization of Bedded Salt Formation and Overlying Areas of the Salina Basin (NUS, 1979b).

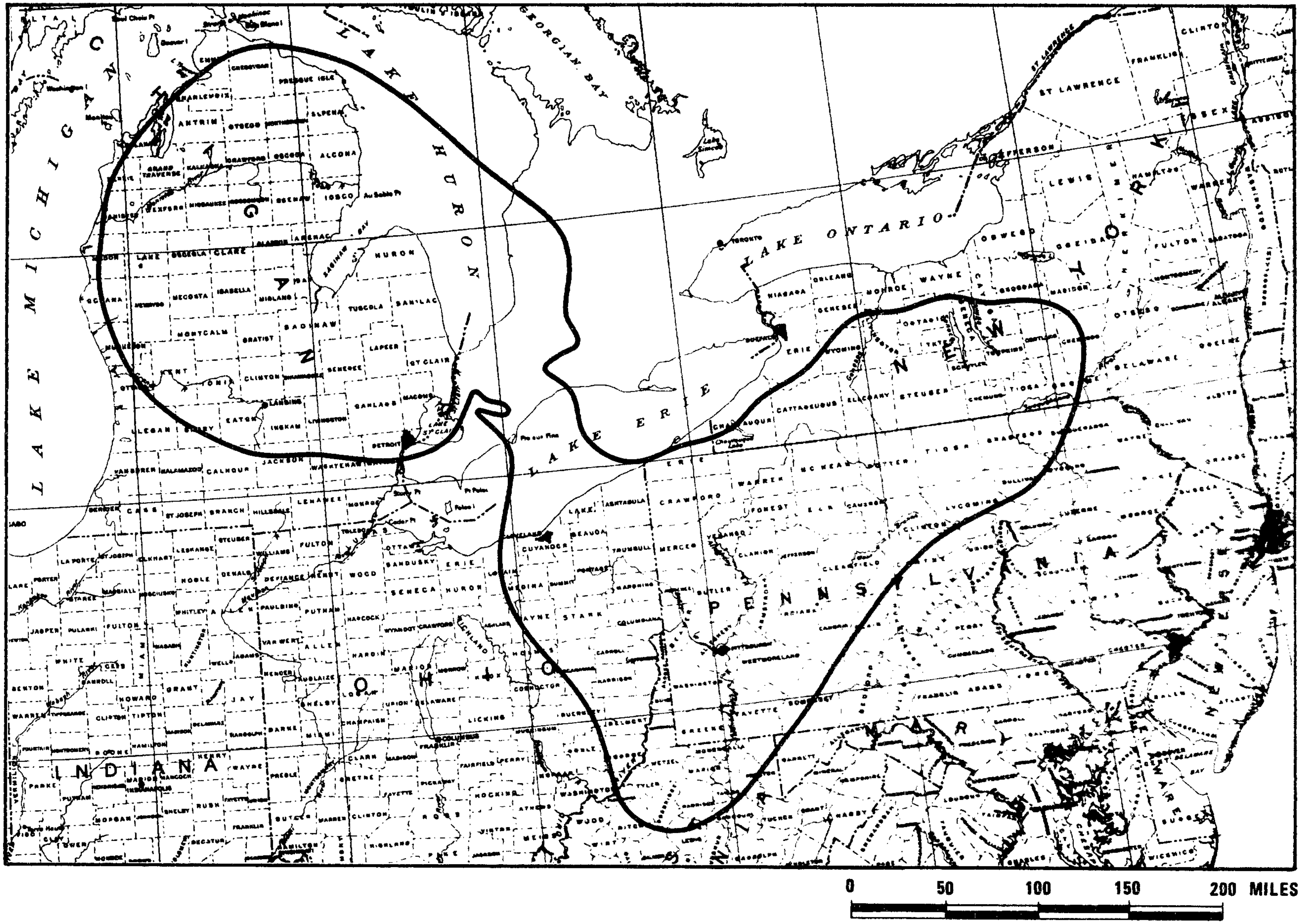

Figure B-2. The Salina bedded-salt region.

as moraines and drumlins, reflect the prominent effects of Pleistocene glaciation in this section. The remainder of the region is a part of the Appalachian Plateaus physiographic province. It is composed of shallow river valleys and broad ridges, with escarpments that provide abrupt changes in elevation. Local elevations generally vary by no more than 300 to 400 feet; however, the elevation increases in going from west to east from about 1000 feet above sea level in Ohio to about 2000 feet above sea level in New York.

The Salina region lies within two major tectonic divisions: the Central Stable region in the west and the orogenic belts of the Atlantic margin in the east. The Central Stable region is founded on Precambrian rocks that compose the stable interior of the North American continent. The eastern areas of the region contain mountainous areas uplifted and deformed during the Paleozoic Era. Separating the eastern and western portions of the region are a series of arches--areas that were stable or gently uplifted and deformed during the Paleozoic Era, when the Appalachian and Michigan basins were subsiding. It was during these periods of subsidence that salt beds were formed. All these structures are extremely old, with no major movements in the earth's crust for approximately 190 million years. Indeed, the Salina region has experienced no major internal tectonic activity since Precambrian time (1 billion years ago). Major structural features within the region are few, uncomplicated, and broad in extent. Minor structures within the region are also relatively few and simple.

The Salina region is one of low seismicity. Earthquakes in the eastern portion of the region are attributed to readjustment of the earth's crust after the most recent Ice Age. Major surface faulting is uncommon. Several seismic events have occurred in the vicinity of Attica in western New York. These earthquakes have been related to the Clarendon-Linden Fault, a north-south-trending tectonic feature. Several moderate earthquakes (modified Mercalli intensity of V) have occurred near Cleveland, Ohio. Portions of the Salina region in Michigan, Pennsylvania, and West Virginia have been virtually earthquake-free.

Oil and gas fields have been developed in all parts the Salina region. Primary, secondary, and tertiary recovery efforts, which include water flooding and fracturing, may have affected portions of the Silurian salt layers. The most abundant oil and gas fields are in Pennsylvania, West Virginia, and Ohio. Major bituminous coal reserves occur in Pennsylvania, West Virginia, Ohio, and Michigan. Much of the coal is within 300 feet of the surface, well above the salt beds. Metallic ores in the region are of low grade and of limited economic importance. Several nonmetallic minerals of economic importance are extracted in the region: salt, salt brines, silica, and construction materials (sand, gravel, gypsum, etc.). With the exception of salt brines, it is not expected that current or future recovery of these minerals would affect waste-repository siting.

B.5.2 Hydrology

The Salina region is subdivided into three Hydrologic Regions (HR): HR I, southeastern Great Lakes basin; HR II, Susquehanna River headwaters; and HR III, northeastern Ohio River basin.

Hydrologic Region I covers the drainage area of Lake Huron, Lake Erie, and Lake Ontario. The terrain is characterized by flat land, lakes, marshes, and peat bogs, reflecting the poor development of regional drainage systems. Streams are relatively short and follow the lows of the once-glaciated terrain. The terrain is therefore more conducive to infiltration than to direct, rapid surface runoff. Water available for withdrawal and use in HR I comes primarily from precipitation within the area. Annual precipitation ranges from 28 to 37 inches; approximately one-third, nearly 12 inches, becomes runoff. Water is generally nonsaline throughout HR I.

Major floods and most damaging floods are usually the result of rain and snowmelt on frozen or nearly saturated ground. Intense summer storms have created destructive floods, but these are ordinarily confined to local areas. Dams are used for flood control and for water-resource management. The largest single use of water in the region is for cooling steam-electricity generating plants. Manufacturing facilities and domestic consumption are also major water users.

Although water-bearing formations underlie all of HR I, the depth to the water table varies with the season, local geologic characteristics, and terrain. With the exception of the lower Michigan Peninsula, productive aquifers (yielding to a well at least 50 gpm of water containing not more than 2000 ppm of dissolved solids) are located only along some of the main watercourse alluvial valleys. Because of the abundance of surface-water supplies in HR I, groundwater usage has not been extensively developed and constitutes generally less than 10% of the total water use.

Hydrologic Region II is located in the headwaters area of the Susquehanna River, which flows southeasterly from south-central New York through Pennsylvania and Maryland. The two major tributaries of the Susquehanna River that flow through HR II are the West Branch of the Susquehanna River and the Chemung River. Hydrologic Region II is characterized by deeply eroded, steep-sided, flat-bottomed valleys and flat to gently rolling plateaus varying in relief from several hundred feet in New York to nearly 2000 feet in Pennsylvania. This type of landscape tends to shorten the time for precipitation to run off into streams and consequently promotes the possibility of flooding. Precipitation averaging nearly 38 inches annually in HR II is the major source of water supply. The mean annual runoff varies from about 15 to 25 inches, about half of this occurring during the 3-month period from March through May. Some tributaries of the West Branch of the Susquehanna River are heavily influenced by acid mine drainage. Nevertheless, the dissolved-solids concentration of most streams in HR II seldom exceeds 800 ppm. Generally, floods occur each year in HR II; major flooding can occur in all seasons. Flooding is, however, more frequent in early spring, usually in March. Major floods have been caused by heavy rainfall on top of heavy snowfall and by heavy rainfall on previously saturated ground. Occasionally, local flooding is caused by ice jams or from thunderstorms during the summer months. As in HR I, major water uses are for steam-electricity generation, manufacturing, and domestic consumption.

The abundant water in the Susquehanna River basin is looked to by communities outside the area as a supply source for the future. Currently significant quantities of water are piped to Chester, Pennsylvania, and Baltimore, Maryland. Rural water supply needs will also increase rapidly in the future. This includes rural domestic use, consumption by livestock, and irrigation.

The increases are not as dramatic as in the urban areas, but they are nevertheless substantial and must be planned for, particularly where they compete directly with urban needs.

Groundwater in HR II occurs in appreciable quantities in rock strata and is generally of good quality, except near coal mines below Tioga County, Pennsylvania. Deep aquifers in the region may be saline or brackish. Highly permeable glacial deposits along most of the valleys are significant sources of groundwater. These aquifers are very productive and readily recharged. Since most urban communities are situated on water-bearing glacial deposits in the valleys, groundwater has not been widely utilized. Although water-use data are not available for HR II, data for the entire Susquehanna River basin, which includes HR II, indicate that 17% of the total water consumption is supplied by groundwater. Total groundwater use is expected to increase as water demands grow in the region.

Hydrologic Region III lies in the northeastern section of the Ohio River basin. Major streams in this region are the Allegheny River, Monongahela River, Muskingum River, Beaver River, and the main stem of the Ohio River. Hydrologic Region III is located in the Appalachian Plateaus physiographic province, which is characterized by a rugged terrain resulting from the differing resistance of the rock to weathering and runoff. Extensive forest cover, poor-quality soils, narrow valleys, steep stream gradients, and flash floods during the dry seasons are characteristic of this area. Vegetation is generally sufficient to retard runoff and minimize erosion. Precipitation averages about 45 inches annually; runoff ranges from about 11 to 25 inches annually. Many minor tributary streams throughout the area normally cease flowing during the dry season, with drought periods adding to their number. Often during late summer and early fall, stream flow from precipitation is negligible, the only flow being from groundwater seepage. Waters of the region are nonsaline, although some tributaries have high concentrations of dissolved solids. In order of gross consumption, major water-usage categories are steam-electricity generation, manufacturing, and domestic use.

Valley-fill sediments, consisting both of glacial outwash and recent alluvium, are the most important source of groundwater in HR III. Highest yields occur generally in the valleys of the Ohio River and its north-side tributaries. Most bedrock systems in the area are relatively poor water bearers, although productive aquifers do occur in some limited rock strata that underlie portions of HR III. High iron concentrations are often found in these waters. Groundwater supplies have been developed in the valley-fill-sediment aquifers primarily for use at the point of need. Because of the large areas covered by these aquifers, most of the stored water has been untouched by current development.

B.5.3 Climate

The Salina region is located primarily within the Great Interior climatic zone. Differences in climate are controlled primarily by latitude, general air mass and storm movements, elevation, and distance to sources of moisture. Modifications to the climatic patterns are introduced by the Great Lakes and by the lifting effects of the Appalachian Mountains. The climate is generally characterized as cool in the northern section and warm temperate and rainy in the southern section. Wind and precipitation patterns indicate a very low erosion potential in the region.

Fundamental changes in the climate of the region have occurred over the last million years (the Pleistocene Epoch). In this period there have been four ice ages, during which glaciers covered much of the Salina region.

The most recent ice age (Wisconsin Glacial) ended about 10,000 years ago, although continuous ice sheets still exist in the polar regions. The current epoch (Holocene) is considered to be interglacial; however, there are indications that a long-term global cooling trend is under way at present.

In the Salina region, severe-weather conditions are rather typical of those occurring in most areas of the contiguous United States. The maximum 24-hour rainfall with a 100-year recurrence interval ranges from 4 to 6 inches. The frequency of tornadoes is noticeably greater in southern Michigan and eastern Ohio than in other sections of the region. However, the frequency is significantly lower than that in the Central United States. Most of the Salina Region experiences 100-year maximum winds of less than 90 mph, which is typical for most of the continental United States.

Restrictive dispersion conditions are relatively frequent in the extreme southern section of the Salina Region compared with the rest of the region and with the contiguous United States. Sections of the Salina Region experience less than 25 to nearly 40 episode-days in 5 years.

Air-quality statutes and regulations restrict development in areas that are not attaining the national ambient air-quality standards (unless certain offset criteria are satisfied) or where emissions would result in violations of the standards or would exceed increments established by the Clean Air Act Amendments of 1977. Data indicate that the national ambient air-quality secondary standards for particulates are being exceeded around all major cities and in eastern Ohio, southwestern Pennsylvania, and northern West Virginia.

B.5.4 Background Radiation

Background radiation is ubiquitous, resulting from cosmic, terrestrial, and fallout sources. Limited data available for the Salina region reveal no anomalous areas. Dose rates range from 68.8 mrem/yr at Charlevoix, Michigan, to 116.7 mrem/yr at Wheeling, West Virginia.

B.5.5 Demographic, Socioeconomic, and Land-Use Systems

Many areas within the Salina region are highly urbanized. The heaviest concentrations of urban areas (over 50,000 inhabitants) in the region occur in Ohio, southern Michigan, and western Pennsylvania. The largest urban areas in or near the region include Detroit (nearly 4 million inhabitants), Cleveland and Pittsburgh (nearly 2 million inhabitants each), and Buffalo (over 1 million inhabitants).

Total earnings for the Salina region in 1970 amounted to 66 billion dollars; by the year 2000 earnings will be about 181 billion dollars. Manufacturing accounted for approximately 41% of the total earnings in 1970. Although agriculture and forestry are the dominant land uses, they produce, together with fisheries, about 1% of the total earnings of the region. Mining and other extractive industries likewise account for about 1% of the regional earnings. Retail and wholesale trade, government, institutions, and other services account for approximately 56% of earnings. This percentage is expected to increase, and the percentage for manufacturing is expected to decrease, in the coming decades.

Sensitive or conflicting commitments of land ar^as larger than 10,000 acres consist of the Allegany Indian Reservation, 10 parks, 8 forests, 3 wildlife refuge, 8 recreation projects, 14 airports, 2 military reservations, and 4 military operations areas. The area committed to these activities totals less than 6% of the Salina region. The bulk of the remaining land is agricultural and open land, with some areas preempted for urban and residential development and for transportation networks.

The Salina region is traversed by a well-developed network of highways, rail lines, and waterways used for commercial transportation.

B.5.6 Terrestrial Ecosystems

The broad mosaic of land-use patterns in the Salina region has a significant influence on the distribution and abundance of terrestrial resources. Major land-use patterns in the region are forestland (44%), cropland (31%), pastureland (6%), and other rural land (6%).

Four ecoregion categories occur in the Salina region: Northern Hardwoods, Beech-Maple Forest, Appalachian Oak Forest, and Mixed Mesophytic Forest. Important natural vegetation includes commercially valuable timber, wetlands, natural areas, and proposed endangered plant species. Commercial forestland in the region is about 90% hardwoods and 10% softwoods. Forestland is about equally divided among sawtimber, poletimber, and seedling/sapling stands. Approximately 2% of the region is classified as wetlands with some importance to waterfowl. Some 28 representative wetland areas and 5 National Wildlife Refuges (predominantly in wetland areas) are located in the region. (Only three wildlife refuges are reported in Section B.5.5 as sensitive or conflicting commitments of land because of the size criterion--10,000 acres or more.) The Society of American Foresters has identified 10 natural areas in the region. Five plant species that are proposed for the Federal list of endangered species occur in the region.

Regional wildlife includes some 65 species of mammals, at least 400 species of birds, and 73 species of amphibians and reptiles. Forestland, shrubland, and openland species are well represented. Important wildlife includes game species, furbearers, and endangered species. At least 31 game birds and 23 game mammals are found in the region, and hunting and trapping are important. The white-tailed deer is the most important big-game animal; rabbits and tree squirrels are important small-game mammals. Nonmigratory game birds include the ring-necked pheasant, bobwhite, and ruffed grouse; migratory game birds include waterfowl and the mourning dove. Species on the

the Federal list of endangered species are the Indiana myotis, Kirtland's warbler, peregrine falcon, and bald eagle.

Farming is important in the Salina region. Major crops are corn, hay, winter wheat, and oats. Cattle, swine, and sheep are important livestock.

B.5.7 Aquatic Ecosystems

The Great Lakes provide the most extensive commercial fishery within the Salina region. Although shifts have occurred in the abundance of various species because of fishing pressures, introduction of predators, and pollution, commercial harvesting of fish remains a significant industry in the Great Lakes. The Ohio River drainage presents a more limited fishery resource. The commercial fish harvest in this drainage may be considered negligible, as are the present-day collections of mussels and clams. The Great Lakes and the Finger Lakes in upstate New York support a diverse sport fishery. Appalachian streams offer trout fishing; in many lower stretches of tributaries and in the main-stem rivers of the Salina region a warm-water fishery exists. Many streams and lakes are augmented with stocked species to enhance sport fishing. Only two fish species and one invertebrate on the Federal list of endangered species occur in the region.

B.6 PARADOX REGION*

B.6.1 Geology

The Paradox region (Figure B-3) is located in southeastern Utah and southwestern Colorado. The entire region encompasses roughly 10,000 square miles; about 60% of this land area is in Utah. The Paradox region is a tectonic unit (Paradox Fold and Fault Belt) of the Colorado Plateau and is also a feature of Thornbury's (1965) rugged Canyon Lands section of the Colorado Plateau. As such, it has a diverse and varied physiography and exhibits the landforms associated with tectonic and igneous activities as well as with extensive wind and water erosion. Most of the region is above 5000 feet in elevation, often with high relief and rugged terrain. The area contains some of the most spectacular scenery in the United States.

The rocks of the Paradox region consist of at least 15,000 feet of clastic and evaporitic sediments resting nonconformably on a basement complex of granitics and metasediments. The age of the basement rocks is Precambrian, while the sedimentary strata range in age from Cambrian to Cretaceous. Disconformities and hiatuses abound, some of very long duration. Ordovician and Silurian rocks, for example, are completely absent, and no marine deposition has occurred since the close of the Mesozoic Era. The only Tertiary rocks of significance are intrusive volcanics. The Quaternary is represented only by fluvial deposits, a substantial amount of wind-blown sediments, and minor amounts of gravel and till.

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*Data from Regional Characterization Report for the Paradox Bedded Salt Region and Surrounding Territory (Bechtel, 1978a).

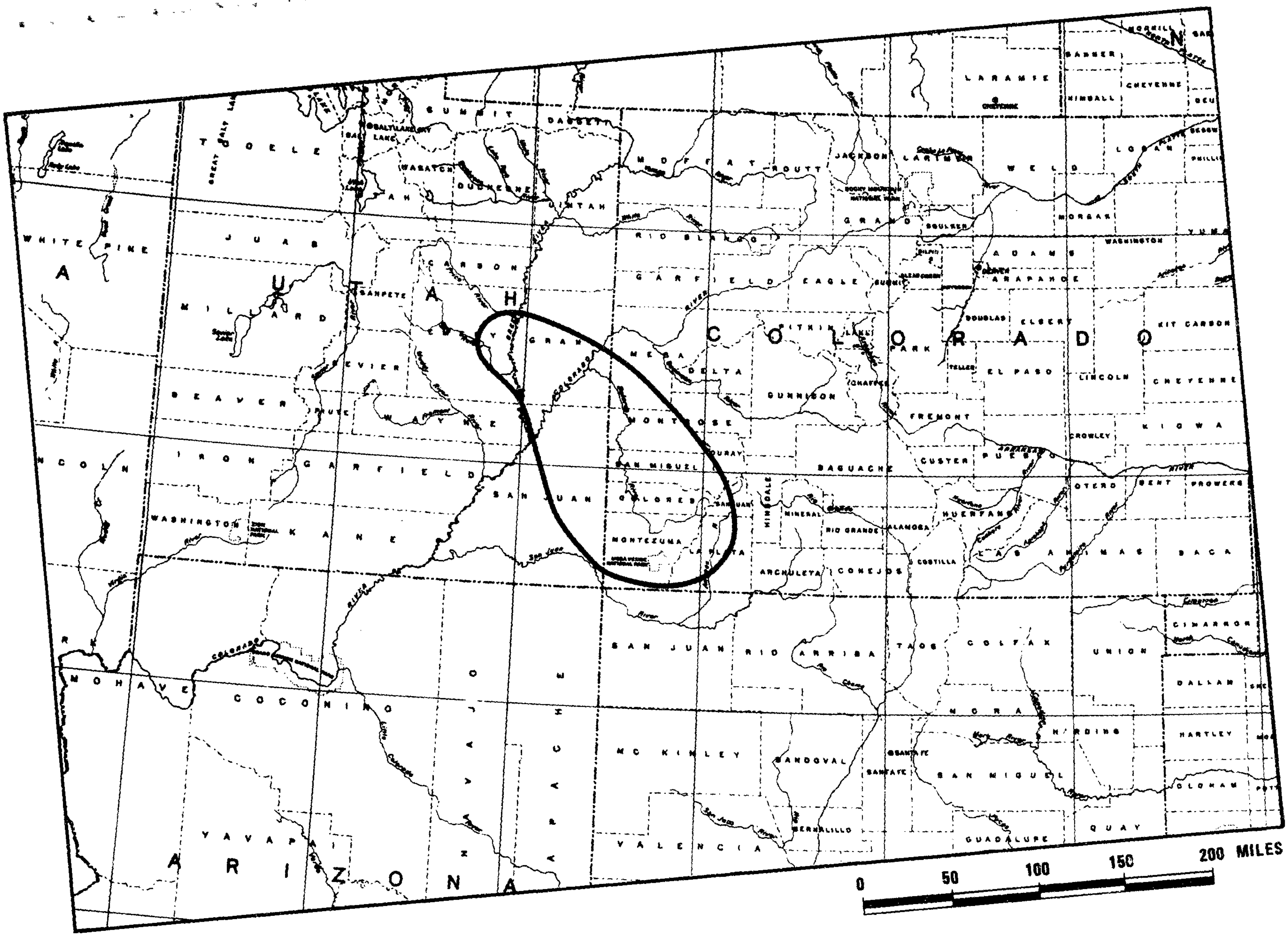

Figure B-3. The Paradox bedded-salt region.

The Colorado Plateau Province, of which the Paradox region is a part, is a mildly deformed platform surrounded by the more highly deformed Rocky Mountains. The principal tectonic elements of the Plateau include uplifts, monoclinal flexures, domes of igneous intrusion, platforms, slopes, saddles, and fold-and-fault belts. In addition, the region displays numerous igneous plugs, diatremes, caldron sinks, dikes, and multitudinous systems of joints and small faults.

The Paradox region is one of low seismic activity. Fifty-four earthquakes with a maximum intensity equal to or greater than V on the modified Mercalli scale of 1931 are known to have occurred in or within 100 miles of the Paradox region from 1853 to 1976.

The tectonic history of the region was eventful. Evidence indicates that the region was under water for a long period of time before the start of the Cambrian period. During the Paleozoic Era much activity occurred, with periods of uplift and erosion alternating with periods of inundation and sedimentation. The formation of the Paradox basin salt occurred during the latter part of this era. By comparison, the Mesozoic Era was relatively quiescent. No major mountain-building activity occurred in the region during the Triassic and Jurassic periods, but the shallow seas moved in and out to deposit occasional layers of marine sediments. The powerful uplifts that raised the Colorado Plateau province to its present elevation began in the last half of the Cretaceous. During the early Cenozoic Era the mountain building continued until the Rocky Mountains were formed. Volcanism was also widespread and frequent during the Cenozoic Era, when most of the prominent surface features of the region were formed.

The Paradox region and surrounding territory have supplied important energy resources for nearly three decades. Petroleum, natural gas, and uranium from this area have made substantial contributions to the nation's energy needs and have played an important role in the local economy. Energy and mineral production is still increasing. A few metals and industrial minerals are also present in the region, but they have been produced on a small scale compared to exploitation of the energy reserves.

B.6.2 Hydrology

Surface water is a valuable resource in the semiarid Paradox region. The principal rivers in the and surrounding territory of the Upper Colorado Water Resource Region (UCWRR) are the Colorado and the Green, and their major tributaries are the Price, San Rafael, Dolores, and San Juan Rivers. No large natural freshwater lakes or wetlands occur in the region. Precipitation is light and varies with ground elevation. Maximum stream flow occurs in late spring; it is due to snowmelt runoff from mountainous areas. Localized flooding can occur, especially when periods of snowmelt coincide with intense thunderstorms. Areas most prone to flooding are along the floodplains of rivers or streams. Most serious damage occurs in broad floodplains where agricultural or urban developments exist. Flood control is accomplished by watershed management and land-treatment programs in the UCWRR. Flood-control reservoirs are normally multipurpose and may provide power generation, irrigation, and recreational benefits. Surface-water quality is generally good, although high dissolved-solids concentrations pose a problem in some waterways of the UCWRR. Water availability is limited, and demand, especially for good-quality irrigation water, is growing.

Groundwater occurs in the Paradox region under both water-table and artesian conditions, and the quality of this water ranges from fresh to near-saturated brines (in excess of 350,000 mg/l of total dissolved solids). Water-table conditions commonly exist in the shallow alluvial aquifers, in recharge areas, and near the surface in relatively flat-lying rocks that are found over large portions of the region. Most of the groundwater underlying the region has dissolved-solids concentrations in excess of 3000 mg/l and is unsuitable for most uses. Usable fresh water is present only in near-surface aquifers and is seldom found at depths greater than 200 feet. The only source of fresh water is precipitation falling on the region; principal areas of recharge are the highlands of the region and other areas where aquifers crop out.

B.6.3 Climate

The Paradox region is largely a cool, semiarid, mid-latitude steppe with isolated areas classified as mid-latitude deserts or humid continental regimes. The region is very dry, with an average annual precipitation of approximately 8.3 inches. The dry conditions provide the region with a relatively high potential for wind erosion.

Fundamental changes in the climate of the region have occurred during the last million years, apparently resulting from changes in global temperature. Four major glaciations occurred during the Pleistocene Epoch, but the region is located more than 500 kilometers southwest of the southernmost limit of the ice cover and was not glaciated.

The region is relatively free from severe-weather hazards and can expect a maximum 100-year rainfall of only 3 inches in a 24-hour period. It is also in an area of low tornado activity; this part of Utah reported no tornadoes from 1955 to 1967. Similarly, high winds are not frequent; a maximum wind speed of about 85 mph has a 100-year mean recurrence interval. However, local channeling effects might alter the maximum speed at specific sites.

Inversions are relatively common in the Paradox region in comparison with the United States as a whole: the region has experienced about 180 episode-days in 5 years. These conditions are related to the terrain of the region, which is a complex system of valleys surrounded by high terrain. This type of terrain allows the formation of frequent temperature inversions that could pose a major problem for the dispersion of emissions from a waste repository. In addition, poor dispersion conditions occur during the frequent stagnation of large-scale high-pressure systems.

With regard to existing air quality (Prevention of Significant Deterioration), all national parks and wilderness areas within the Paradox region are classified as Class I areas. The remainder of the region is a Class II area. The law generally allows no or minimal industrial development in Class I areas and moderate development in Class II areas.

B.6.4 Background Radiation

Virtually no data specific to the Paradox region are available. In general, the mountain states are higher than the national average in both natural terrestrial and cosmic background radiation, although the regional variations appear to be of minor significance.

B.6.5 Demographic, Socioeconomic, and Land-Use Systems

The Paradox region is a rural area with many small towns of less than 1000 people scattered along highways. Farmington, New Mexico, and Grand Junction, Colorado, are the only two cities in the areas adjacent to the region with more than 20,000 inhabitants. There are no cities this large within the region. The total population of the region was approximately 240,000 in 1970. Most of the counties in the region showed a 10 to 20% increase in population between 1970 and 1975.

The economy of the region is dependent on the continued long-term development of extractive industries and the processing of petroleum, coal, molybdenum, vanadium, natural gas, and other mineral and energy resources. Growth in these and related support industries will, to a large extent, determine the rate of economic growth for the region, primarily because of their export value.

Agriculture is also important in the region, although productivity is limited by local climatic factors. The low annual rainfall, combined with areas of marginal soil productivity, limits agricultural activities to livestock grazing and local hay and grain production. Livestock is the only major agricultural product exported from the region. Other industries are of lesser importance.

Land uses of interest include Federal and state recreational and natural areas (which occupy 29% of the land area within the region), urban areas (less than 1%), and Indian lands (16%). The bulk of the remaining land is open range, with small areas preempted for transportation networks.

B.6.6 Terrestrial Ecosystems

The Paradox region contains vast areas of relatively undisturbed natural habitat. Fifteen natural vegetation systems occur in the region; these range from pine or fir forests to scrublands, steppes, and barrenlands. Six ecological reserves have been established or proposed for the region; these "natural areas" would insure the preservation of a typical or unusual vegetation type in as near an undisturbed condition as possible. A great variety of wildlife inhabits the region, including many furbearing species, numerous big- and small-game species, and several threatened or endangered species.

Major range types within the region include grasslands, three types of desert shrubs, and pinyon-juniper woodlands. This range is well utilized, and the market value of livestock is normally 50 to 60% of the value of all agricultural products in the region. Lands having good soil on moderate slopes are generally dry-farmed or irrigated. A variety of crops are grown; these typically account for 40 to 50% of the market value of all agricultural products. Although extensive forested areas occur in the region, forest products contribute less than 1% of the total value of all agricultural crops.

B.6.7 Aquatic Ecosystems

Most aquatic habitats in the Paradox region are cold-water trout streams, generally above 5000 feet in elevation. The native game fish, mainly cutthroat trout and whitefish, have been largely replaced by introduced game species, principally rainbow trout. Very little warm-water-stream habitat is found in the region; the warm-water habitats that do exist frequently contain both cold- and warm-water fish species. Although a considerable number of sport fish are taken annually, the fishery resource is relatively poor because of the high sediment load of many streams. Four threatened or endangered fish species have been identified in the region; all are found in the Colorado River or its tributaries.

B.7 GULF INTERIOR SALT-DOME REGION*

B.7.1 Geology

The Gulf interior region of Alabama, Mississippi, Louisiana, and Texas lies within the Gulf Coastal Plain physiographic province (Figure B-4). It includes parts of 11 major physiographic subdivisions.

The basement of the Gulf interior region consists of structurally deformed incipient or weakly metamorphic late Paleozoic and older rocks and crystalline materials of unknown age. These rocks are overlain by a great thickness of Mesozoic and Cenozoic that regionally thickens in successive wedges toward the Gulf. The top of the Paleozoic basement occurs at depths of about 13,000 feet at the northern boundary of the region and reaches almost 30,000 feet in depth at the southern limit. Local structure modifies this general trend.

The region lies within a large structural downwarp known as the Mississippi Embayment, which extends north into southern Illinois, east into Alabama, south to the vicinity of Baton Rouge, Louisiana, and as far west as eastern Texas. A variety of smaller structural elements modifies this general framework and defines the immediate structural parameters of the storage rock unit. These features include basins and domes or uplifts, flexures and faults, and salt domes.

The region is one of low seismicity. Within 100 miles of the Gulf interior region there were only 20 earthquakes between 1886 and 1974 whose maximum intensities were equal to or greater than V on the modified Mercalli scale of 1931.

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*Data from Regional Environmental Characterization Report for the Gulf Interior Region and Surrounding Territory (Bechtel, 1978b).

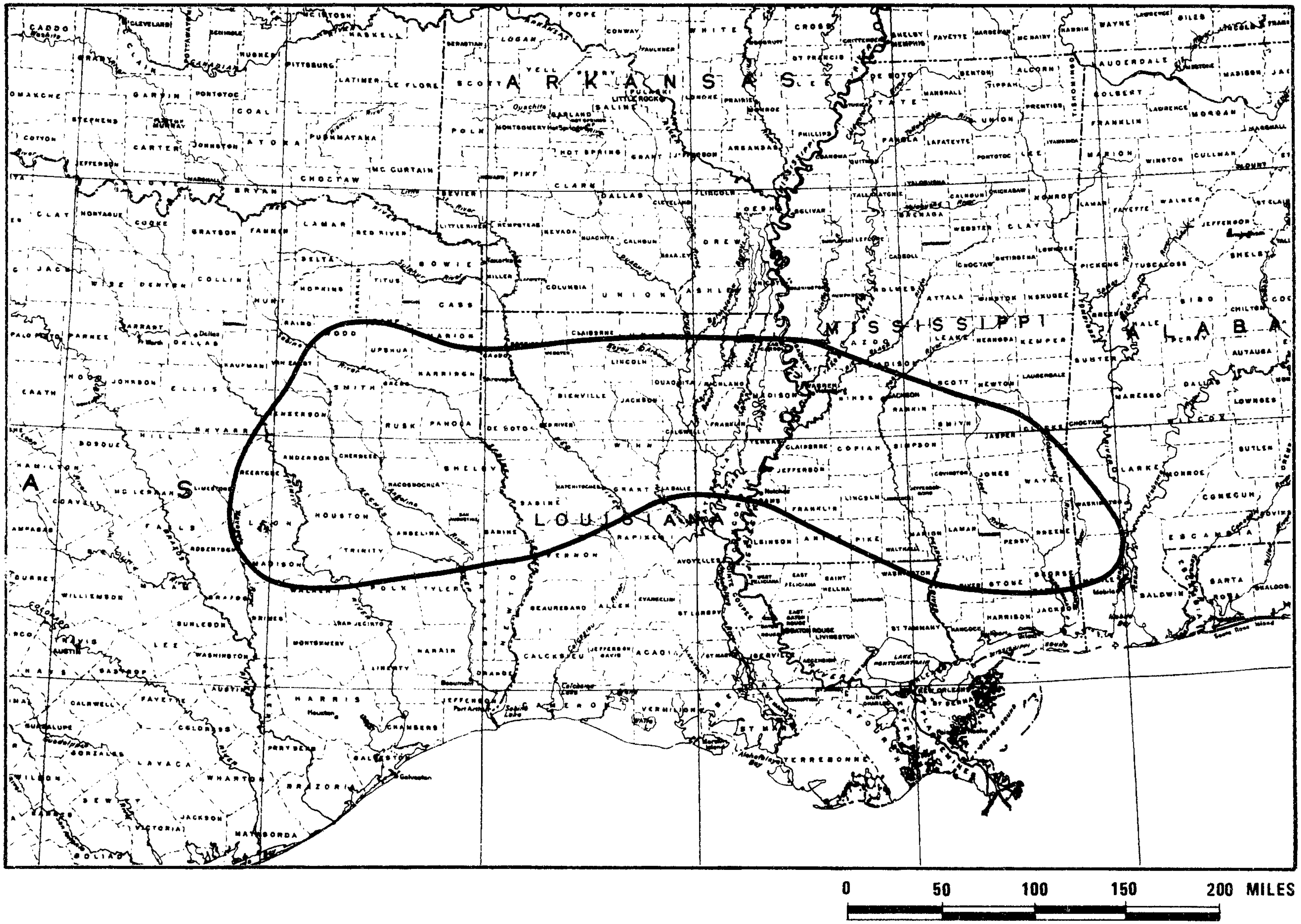

Figure B-4. The Gulf interior salt-dome region.

The early tectonic history of the Gulf Coastal area before Jurassic time is conjectural because of lack of data. Currently, there are two trends of thought concerning the origin of the Gulf. One theory holds that the Gulf in some form existed since late Precambrian; the more popular theory holds that the Gulf was initiated by plate tectonics (sea-floor spreading) during early Mesozoic. By early Jurassic time, marine water had entered the area from the west, and a major evaporite-deposition cycle was initiated. At this time the area was probably landlocked. By the late Cretaceous, the area was open to the sea, and the salt deposition had ceased. Various episodes of uplift prior to the Recent (Holocene) Epoch have resulted in the deposition of up to as much as 30,000 feet of material.

Oil and natural gas are the chief mineral industries of the area and have been for the past 50 years. However, other industries, based on processing such materials as ceramic and nonceramic clays, iron ore, and salt, are also well developed in relation to available markets.

B.7.2 Hydrology

The surface-water resources of the Gulf interior region can best be summarized by briefly reviewing the surface-water characteristics of each of four Water Resource Regions (WRRs): the Arkansas-White-Red, Texas Gulf, Lower Mississippi, and South Atlantic Gulf Regions. The various surface-water parameters described for each WRR--including precipitation, runoff, flood history, and surface-water quality, availability, and demand--may vary significantly between and within WRRs.

The Arkansas-White-Red Region (AWRR), which consists of 265,000 square miles in Oklahoma, Louisiana, Arkansas, Texas, Missouri, Kansas, New Mexico, and Colorado, intersects only a small midwestern portion of the Gulf interior region. Precipitation and runoff decrease greatly from the humid eastern areas to the semiarid western areas of the AWRR. The AWRR averages 3200 to 113,000 cfs of runoff, with the maximum stream flow generally occurring from April to June. Major rivers include the Arkansas, White, Red, and Canadian. Eastern lowlands of the AWRR are subject to severe rainstorms and recurrent flash flooding; flooding in the western and central portions results from intense and infrequent rainstorms of short duration. Flood-control problems have been reduced, particularly in eastern areas, by the construction of numerous reservoirs along major rivers. Surface-water quality in several major waterways of the AWRR is poor because of widespread natural and man-induced pollution, including natural mineralization, mine discharges, erosion, and municipal and industrial effluents. The availability of many AWRR surface waters for agricultural, municipal, industrial, and recreational uses is severely limited by the low quantities and qualities of surface waters in some parts of the AWRR. In general, most water supplies are derived from groundwater sources in the western and central AWRR.

The Texas Gulf Region (TGR), which consists of 173,000 square miles in Texas, Louisiana, and New Mexico, intersects roughly one-third of the western Gulf interior region. Precipitation and runoff decrease dramatically from the Texas Gulf Coast northwest to the central and western areas of the TGR. Average runoff is 30 million acre-ft/yr and is principally from the eastern one-fourth of the TGR. Major rivers in the TGR include the Sabine, Neches, Trinity, and Brazos. Flooding in the TGR typically results from tropical storms originating in the Gulf of Mexico; the largest floods have occurred in late summer and early fall from hurricanes. Total-dissolved-solids concentrations in the TGR vary from less than 100 to over 2500 mg/l, with the upper reaches of the Brazos River having the poorest water quality observed. Approximately half the TGR's water needs are met from surface-water sources, and surface-water use is expected to triple by the year 2020. Although the regional supply of surface water is expected to meet that demand, the unequal geographic distribution of surface-water supply and demand may pose problems.

The Lower Mississippi Region (LMR) consists of about 102,700 square miles in Louisiana, Mississippi, Arkansas, Missouri, Tennessee, and Kentucky; it intersects the central quarter of the Gulf interior region. Average annual precipitation varies from 64 inches along the Gulf Coast to 44 inches in southern Missouri. Runoff is rather uniform throughout the LMR, decreasing from 26 to 14 inches per year from coastal to central areas, respectively. Roughly 116,380 cfs of annual discharge is generated within the LMR. Major rivers include the Mississippi, St. Francis, White, Arkansas, and Yazoo. Flooding generally results during late winter or spring from heavy rains and rapid snowmelt throughout the Ohio and Mississippi River valleys or in late summer or early fall from tropical storms and hurricanes along the Gulf Coast. Areas subject to flooding are floodplains and adjacent areas of the Mississippi River, its major tributaries, and coastal areas. By 1970, LMR flood-control storage totaled 6,028,000 acre-feet, and over 3780 miles of levees and floodwalls were in place. Surface-water quality throughout the LMR is variable and dependent on location; in general, however, most streams have good natural quality. Varying degrees of man-induced pollution require selective use and some pretreatment of surface waters in some areas of the LMR. The LMR is one of the most water-rich WRRs in the United States, with 85 million acre-feet of runoff generated within the LMR and a total of 485 million acre-feet discharged annually from its waterways into the Gulf of Mexico. Large increases in surface-water demand are projected by the year 2020, and no shortages are expected.

The South Atlantic-Gulf Region (SAGR) consists of 276,000 square miles in South Carolina, Florida, Virginia, North Carolina, Georgia, Alabama, Louisiana, and Mississippi; it encompasses roughly the eastern third of the Gulf interior region. Precipitation is generally plentiful and uniformly distributed throughout the SAGR. Average runoff is 305,000 cfs. Seasonal highs in runoff occur from November to April and from June to October, resulting from broad cyclonic disturbances and tropical hurricanes, respectively. Major rivers in the SAGR include the Alabama, Tombigbee, Apalachicola, Santee, and Altamaha. Widespread, disastrous flooding is uncommon, although an estimated (in 1968) additional 3.3 million acres of land require flood protection by 1980. Seasonal flood potential is highest from December to April and from August to October. Areas most prone to flooding include the floodplains of major rivers and coastal areas. Numerous watershed and flood-control projects have been constructed throughout the SAGR for flood protection. Natural surface-water quality is generally excellent, with dissolved-solids concentrations averaging less than 100 mg/l. In some coastal plain streams, high turbidity and high sediment loads are not uncommon. In some localized areas, municipal, industrial, and agricultural sources of pollution have caused restricted use of surface waters and an increased reliance on upstream reservoir storage and groundwater for municipal water supplies. Because of abundant surface-water and groundwater supplies within the SAGR, no current or projected water shortages are expected.

Good-quality groundwater is present throughout the Gulf interior region, and it is used extensively for domestic, municipal, and industrial purposes. Several aquifers or hydrologic units are recognized in the post-Cretaceous coastal plain sediments. They comprise a thick sequence of interbedded sands, clays, and marls in which the more permeable materials provide aquifers confined between the less permeable clays and marls. Important water-bearing units or aquifers in the region include the Wilcox-Carrizo units, the Sparta (Kosciusko) Formation, Miocene sands, and Pleistocene to Recent alluvial valley deposits. The water-bearing formations receive recharge in their outcrop areas from precipitation and stream flow, although under present conditions the aquifers are full, and most of the water available for recharge is rejected, moving laterally and discharging to low stream valleys.

B.7.3 Climate

The Gulf interior region lies within a humid temperate zone with moderately high winter temperatures and moderate amounts of rainfall throughout the year. These conditions indicate a relatively low potential for wind erosion.

Although this area has experienced significant temperature decreases (9-28.8°F) in the recent geologic past, indications of glaciation within that period are absent. In fact, the previous glacial boundary appears to be more than 435 miles north of this region.

Severe-weather occurrences in the Gulf interior region generally take the form of high winds and precipitation associated with hurricanes that intrude inland from the Gulf of Mexico. The 100-year-recurrence events for these two meteorological phenomena are 11 inches of precipitation within a 24-hour period and winds of 90 mph. Another severe-weather phenomenon experienced in this region is the occasional tornado (ranging from 6 in a 12-year period on the Louisiana-Mississippi border to 43 or more in portions of northeast Texas during the same period).

Generally moderate mixing levels together with moderate wind speeds and rolling terrain make the Gulf interior region unlikely to experience inversions. Stations within and near this region have reported 13 to 28 episode-days of poor dispersion within a 5-year period.

The region, like most of the country, experiences periods when the national ambient air-quality standards (NAAQS) for particulates are exceeded. Trends in air quality, as evaluated by the Environmental Protection Agency (EPA), indicate a very gradual improvement in this condition in the Gulf interior region, primarily as a result of improved pollution-control technology. There are also a number of areas within this region that have been designated by the EPA as areas of concern for the control of photochemical oxidants. In most cases, these areas, consisting of large metropolitan sites and their immediate surroundings, are presently exceeding NAAQS for this pollutant.

With regard to the Prevention of Significant Deterioration, the region lies within a Class II area, which allows for moderate industrial development. The nearest (presently defined) Class I areas are more than 100 miles away.

B.7.4 Background Radiation

Data for approximately 38 locations in the Gulf interior region and surrounding territory indicate that the region is about average in natural terrestrial and cosmic background radiation. The highest reported background radiation values are in Texas, but regional variations appear to be insignificant.

B.7.5 Demographic, Socioeconomic, and Land-Use Systems

In eastern Texas, the Gulf interior region is a rural area with many small towns. The major cities within the area are Tyler and Longview, but large urban areas such as Dallas, Fort Worth, Waco, and Austin are adjacent to the region. Approximately 75% of the population is white; the remaining is black (except for the 0.7% that is Indian, Chinese, Japanese, or other). The total population of the area was 766,154 in 1970, and most of the counties showed a population-growth rate of more than 7% between 1970 and 1975. Per capita income for the region was $3119.

The Gulf interior region in Louisiana encompasses 298 parishes in the northern part of the State and includes the cities of Shreveport, Monroe, and Alexandria. The total population of this area was 1,062,685 in 1970. Population growth was slower in Louisiana than in Texas, and many parishes had a net decline of up to 10% between 1970 and 1975. Annual per capita income in 1974 for the region was $2788.

There are 35 counties in the Gulf interior region in Mississippi. The largest cities in the region are Jackson, Meridian, Hattiesburg, and Vicksburg. The total population for the area was 778,158 in 1970 and increased to 1,064,217 (estimated) in 1975. Six counties experienced a decline in population between 1970 and 1975, and counties other than those having the major cities mentioned above had a slower growth rate than the rest of the nation and the slowest for all states in the Gulf interior region. Nearly 66% of the 1970 population was white, 34% was black, and less than 1% was of other origin. Per capita income grew by 50 to 70% between 1969 and 1974, and the regional average annual per-capita income was $2826 in 1974.

The economy of the eastern Texas region is largely resource oriented. Extractive industries such as mining, petroleum, and natural gas extraction, manufacturing based on regional resources, and agriculture comprise the core of the export economic base. In rural counties in eastern Texas, tourism is an important element in the local economy. Mining and manufacturing activities account for 33% of the total employment. Eastern Texas is a producer of agricultural crops and livestock; some counties produce considerable amounts of livestock and poultry for export to other states.

Much of the region in Louisiana is rural and is used for agricultural crops, grazing, or forests. More than 64% of the total employment is located in the Shreveport, Monroe, or Alexandria urban areas. The State is one of the largest producers of natural gas and petroleum. Manufacturing is located near the larger urban areas, and industries based on lumber and wood products, food products, primary metal products, fabricated metal products and appliances, textiles and apparel, and chemicals all have notable employment. In 1970 the agricultural production of crops was centered in the lowland region along the Mississippi River; livestock production was concentrated in upland areas. Total agricultural income in 1974 was $445 million, up 114% from 1969, with approximately 70% attributed to crops and hay.

Manufacturing accounts for 31% of the total employment in the Mississippi portion of the Gulf interior region and represents the largest single employment sector. Extractive industries (natural gas and petroleum, sand and gravel, and other minerals) employ less than 20% of the labor force. Agriculture is also a significant contributor to the local economy. Lowland counties of the Mississippi River basin are intensively cultivated for field and row crops; upland counties are extensively used for livestock grazing.

The majority of the population in the eastern Texas Gulf interior region lies in the Tyler and Longview urban areas. As much as 10% of the area is in urban uses, and the average population density throughout the area is 0.02 person per acre. Vast expanses of woodlands and agricultural land characterize the area. Eastern Texas has three national forests totaling 507,012 acres: Angelina, Davy Crockett, and Sabine. Recreational uses of lakes and reservoirs and parks in the area are rapidly growing, and second-home development around some lakes (i.e., the Cedar Creek Reservoir) has occurred recently. The Federal Government maintains and is acquiring jurisdiction over sizable land areas to meet growing demands for various recreational uses. Airports are common throughout eastern Texas; restricted or prohibited airspaces with various altitude and aircraft-operation limitations are also present. Highway and rail systems are extensive throughout the area. One Indian reservation exists in Polk County, Texas.

In Louisiana most urban land in residential, commercial, and industrial uses is around the cities of Shreveport, Monroe, and Alexandria. Outside these urban areas, small towns are numerous, but rural areas are, for the most part, devoted to agriculture or forests. Upland parishes in northwestern Louisiana have less field and row crops and more livestock-grazing land than do lowland parishes along the Mississippi River. The Kisatchie National Forest is distributed in several parcels throughout Louisiana; the total acreage of all parcels is 500,302 acres, or 6.1% of the land in the area. State fish and wildlife management areas and state forests provide abundant recreational uses. Airports of varying size are found throughout the area; restricted and prohibited airspaces with varying limitations are also present. Rail and highway systems are well developed in all of Louisiana. One Indian reservation is located in the area.

The largest cities in the Gulf interior region in Mississippi are Jackson (166,572), Meridian (46,256), Hattiesburg (38,097), and Vicksburg (29,726). Like Louisiana, the area is largely rural, with agricultural lands predominating. Five national forests in the area cover 1.7 million acres, or 15% of the area. Many types of uses are provided, including recreation as well as timber harvesting. Airports of various sizes are found throughout the area, as are restricted airspaces. Rail and highway systems are well developed. One Indian reservation is located in Leake County, outside the Gulf interior region.

B.7.6 Terrestrial Ecosystems

In the Gulf interior region and surrounding territory in Texas there are nine potential vegetation types, ranging from mixed hardwood-softwood forests to open prairies and savannahs. No ecological reserves have been established in the basin, but a number of locally administered natural areas do insure preservation of habitats in as near an undisturbed condition as possible. Important animal species include approximately 9 furbearers, several game animals, and 20 protected, threatened, or endangered species.

Major range types in the Texas Gulf interior region include grasslands, shrublands and chaparral, and pinyon-juniper woodlands. The rangeland has a relatively high productivity compared to the typical western range, and livestock and livestock products accounted for the highest portion of all agricultural products sold in the Texas Gulf interior region in 1974 (47%). This was followed by poultry and poultry products (36%), crops and hay (12%), nursery and greenhouse products (3%), and forest products on farms (1%). Harvested hay, sorghum, and cotton were the crops covering the greatest land area in 1974. Commercial forests in counties within the east Texas Piney Woods region cover about 63% of the region. Forest types with the most coverage are loblolly-shortleaf pine, oak-pine, and oak-hickory.

Only four potential vegetation types occur within the Gulf interior region of Louisiana--prairie and three kinds of mixed hardwood-and-softwood forests. However, the variation within these vegetation types, due to man's activities as well as the natural soil and climatic variations, contributes to diverse wildlife habitats. In addition to one ecological reserve, the Bayou Boeuf Natural Area, there are several State, private, and Federal wildlife areas. Important animal species include approximately 13 furbearers, 11 game mammals, and 6 threatened or endangered species.

Livestock grazing occurs on cultivated pasture as well as in forested lands. Livestock and livestock products represented only 18% of the value of agricultural products sold in 1974. Principal livestock types produced in the area in 1974 were beef and dairy cattle. Livestock productivity varies throughout the area, as does the productivity of agricultural crops and timber resources, the most productive livestock parishes being De Soto, Caddo, Richland, Natchitoches, and Rapides. Agricultural crop production was largest in Morehouse, East Carrol, Madison, and Avoyelles Parishes; crops and hay represented 70% of all agricultural products sold in the Louisiana Gulf interior region in 1974. Cotton was the crop with the largest harvested area, followed by soybeans, rice, corn, sorghum, wheat, and sugarcane. There are three major forest types in Louisiana: southern pine, upland hardwood (oak-hickory), and bottomland hardwood. Commercial southern pine forests are mostly longleaf and slash pines in the southern half of the State and shortleaf and loblolly pines in the north. Bottomland hardwoods include such species as oak, gum, cypress, elm, ash, and cottonwood. The production of timber resources was highest in Ouachita, Caldwell, Winn, Natchitoches, Sabine, and Caddo Parishes.

In Mississippi, as in Louisiana, there are only four potential natural vegetation types, but one, the blackbelt, is limited to the Gulf interior region of Mississippi and Alabama. Six ecological natural areas have been established in the Gulf interior region of Mississippi for the preservation of vegetation types and wildlife habitat. Important animal species include approximately 11 furbearers, 11 game animals, and 13 species on the Federal list of threatened and endangered species.

In the Mississippi Gulf interior region, poultry and poultry products accounted for the highest portion of all agricultural products sold in 1974 (45%), followed by crops and hay (30%), and livestock and livestock products (22%). Rangeland and wooded pasture are extensively distributed throughout the area. Soybeans, hay, and cotton were the crops with the largest harvested area in 1974. Commercial forests are extensive, covering about 62% of the land area in Mississippi. Commercial forests with the largest areas are oak-hickory, loblolly-shortleaf pine, oak-pine, and oak-gum-cypress.

B.7.7 Aquatic Ecosystems

The Gulf interior region is noted for its extensive and valuable recreational and commercial warm-water stream and lake fisheries. Stream and lake habitats in the region can be divided into bottomland and upland habitat types. Bottomland habitats are generally in the larger, deeper, slow-moving, and turbid streams and rivers that meander through the interior region. Upland habitats are generally in the smaller, faster-moving creeks and streams that are the tributaries of the major waterways within the region. Six endangered fish species have been identified in the Gulf interior region; all six species are found in the State of Mississippi.

B.8 THE HANFORD SITE*

The Hanford Site is a 600-square-mile tract in the southeastern part of Washington State. It is semiarid, and the closest population center is Richland, 5 kilometers to the south.

B.8.1 Geology

The Hanford Site is in the Columbia Plateau physiographic province, which is characterized by the occurrence of a thick sequence of tholeiitic basalts and varies significantly in topographic expression as well as structure (Figure B-5). The Columbia basin section is a broad geologic and structural basin in the interior of the province; the Hanford Site is located in the Pasco basin, which is one of several subbasins.

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*Source: Private communication from K. R. Fecht, Rockwell Hanford Operations, December 1978.

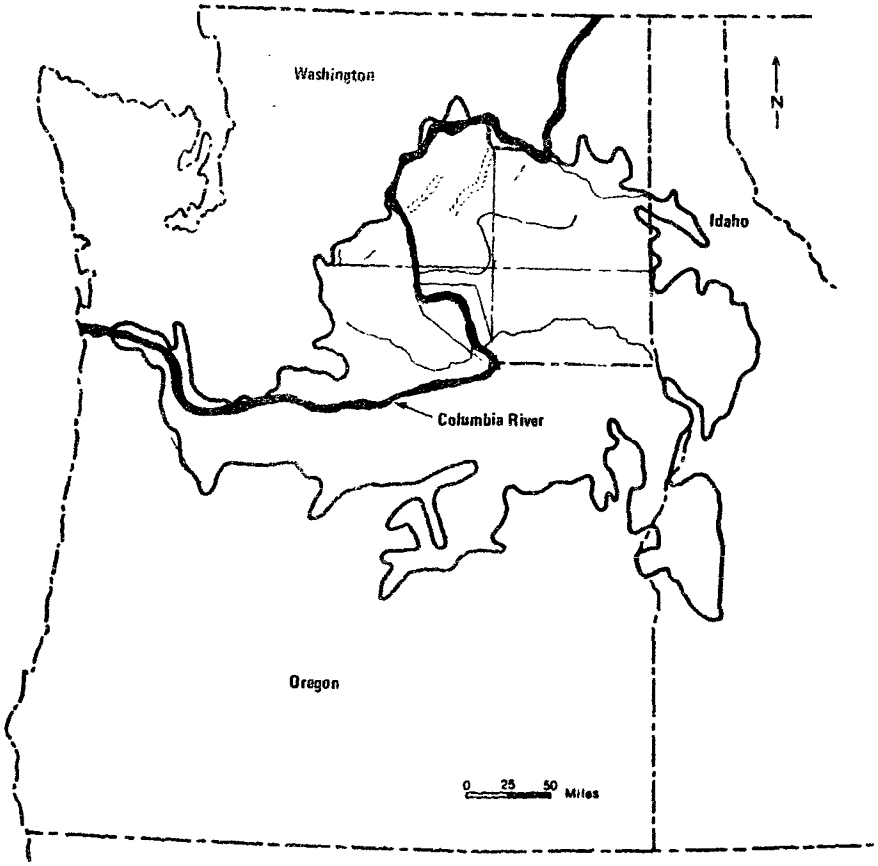

Figure B-5. Location of the Columbia Plateau basalts.

The Columbia basin contains the Channeled Scablands formed at the close of Pleistocene glaciation by multiple catastrophic floods. The floods occurred as ice-dammed lakes released torrents of water and ice when the ice dams were breached.

The regional geology is dominated by Cenozoic rocks and structures. During the Cenozoic Era, numerous basalt magma outpourings from extensive fissure systems flowed across the Columbia Plateau and into regional areas of subsidence, such as the Pasco basin, where thick sections of basalt accumulated. The thickness of the basalt sequence is an average of 1800 feet in the Columbia Plateau and is more than 10,000 feet in the Pasco basin. The frequency and size of the eruptions decreased and then ceased during the late Tertiary period (about 6 million years before the present).

Regional subsidence continued and was accompanied by regional north-south compression, which has resulted in folding of the basalt sequence and in the formation of a number of roughly east-west-trending anticlinal ridges in the central part of the Columbia Plateau. At the Hanford Site, this ridge system is represented by the Rattlesnake Mountains, the Yakima Ridge, and the Umtanum-Gable Mountain Ridge.

Within and on top of the basalt sequence are sedimentary deposits. The interbeds between basalt flows consist of tuffs, tuffaceous sediments, and, in some locations, stream-carried sediments. Interbeds are more prevalent in the upper part of the basalt sequence.

The top of the basalt sequence is covered with fluvial, glaciofluvial, and eolian deposits. In the Pasco basin, the basalt is covered by up to 1000 feet of fluvial sediments (the Ringold Formation) overlain with up to 300 feet of glaciofluvial sediments (informally named the Hanford Formation). Eolian deposits overlie the Ringold Formation in the western part of the Hanford Site. The basement rocks below the basalt sequence are of uncertain composition but are probably sandstones and shale. Granitic rocks are probably below that.

Mineral resources are sand and gravel, basalt, and possibly natural gas. Natural gas has not been detected in the recent drilling of deep boreholes.

The Columbia basin is a region of low seismicity in which moderate earthquakes have occurred. Microseismic activity at the Hanford Site indicates low levels of stress relief, generally shallow focal depths, and no obvious relationship to any geologic structure. The maximum known earthquake intensity in the vicinity of the site was less than IV on the modified Mercalli scale.

Faults in the region are associated with folds in the basalt and appear to reflect local adjustments to folding. They are relatively short in length (less than 30 miles), with generally small displacements (less than 500 feet).

B.8.2 Hydrology

The Pasco basin is a series of confined aquifers overlain by an unconfined aquifer. The area is bounded by ridges to the north, south, and west and by a broad regional monocline to the east.

The confined aquifers are primarily the permeable interbeds and interflow zones in the basalt sequence. The interflow zones are characterized by vesicular rock or by interconnected fracturing caused by rapid cooling of the basalt magma. There is very little hydraulic interconnection between aquifers since the central volume of the basalt flows is dense and has a very low permeability. Fractures in the basalt have been filled with secondary mineralization products such as montronite. The confined aquifers are recharged by precipitation, stream runoff, and infiltration from the overlying unconfined aquifer or distant recharge points. Discharge of the upper aquifer is to the Columbia River.

The unconfined aquifer occurs above the basalt sequence up to about the top of the Ringold Formation. The groundwater movement is distorted by local geologic structures and has been modified by waste-disposal activities at the Hanford Site.

Between the top of the unconfined aquifer and the land surface is the vadose zone. This unsaturated zone is up to about 300 feet thick and is extremely dry below about 30 feet. In this desiccated zone, there is nearly no downward movement of water.

B.8.3 Climate

The climate of the Columbia basin region is dominated by the Cascade Mountain Range to the west and by the prevalent direction of storm fronts from the Pacific Ocean. Summers are relatively hot and dry, most of the average 6 inches of precipitation falls during the winter, and there are occasional periods of high winds. Prevailing winds are from the northwest.

Tornadoes are infrequent. It has been estimated that the probability of a specific surface structure's being hit by a tornado is only 6 in one million.

Thunderstorm activity is low. The estimated annual lightning strike frequency is 0.022 for a typical Hanford building.

B.8.4 Demography

There are an estimated 250,000 people within 50 miles of the Hanford Site. The estimated mean growth rate to the year 2000 is 0.7%.

B.8.5 Historic and Archaeological Sites

There are five locations listed as historic sites or as natural landmarks within 50 miles of the Hanford Site. None are on the site. There are over 200 Indian archaeological sites in the Hanford area, and many of them are along the Columbia River where it passes through the Hanford Site.

B.8.6 Ecology

The ecological aspects of the Hanford Site are consistent with the semiarid climate. The principal plant community is the sagebrush-cheatgrass-bluegrass association; mammals include the coyote, the rabbit, mule deer, and small rodents; birds include the chukar partridge, western meadowlark, migratory ducks and geese, and several species of predatory birds. There are several thousand insect species and about 15 species of snakes and lizards. The aquatic ecosystem consists of the Columbia River and a few ponds and ditches.

Rare, threatened, and endangered species inhabiting the Hanford [illegible]ce include three plant species and seven bird species. The status of some of the latter has not been determined.

REFERENCES

Bechtel, 1978a. Regional Environmental Characterization Report for the Paradox Region and Surrounding Territory, ONWI/Sub/78/512-01600-2, prepared by Bechtel National, Inc., for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

Bechtel, 1978b. Regional Environmental Characterization Report for the Gulf Interior Region and Surrounding Territory, ONWI/Sub/78/512-01600-1, prepared by Bechtel National, Inc., for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

NUS, 1979a. Environmental Characterization of Bedded Salt Formation and Overlying Areas of the Permian Basin, ONWI-27, prepared by NUS Corporation for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

NUS, 1979b. Environmental Characterization of Bedded Salt Formation and Overlying Areas of the Salina Basin, ONWI-16, prepared by NUS Corporation for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio.

DOE (U.S. Department of Energy), 1979. Nuclear Waste Management Program Summary Document, Washington, D.C.

Thornbury, W. D., 1965. Regional Geomorphology of the United States, John Wiley & Sons, Inc., New York.

Appendix C

PRESIDENT CARTER'S MESSAGE TO CONGRESS ON THE MANAGEMENT OF RADIOACTIVE WASTE

AND

THE FINDINGS AND RECOMMENDATIONS OF THE INTERAGENCY REVIEW GROUP ON NUCLEAR WASTE MANAGEMENT

Appendix C

PRESIDENT CARTER'S MESSAGE TO CONGRESS ON THE MANAGEMENT OF RADIOACTIVE WASTE

AND

THE FINDINGS AND RECOMMENDATIONS OF THE INTERAGENCY REVIEW GROUP ON NUCLEAR WASTE MANAGEMENT

Two documents have been especially important in establishing a national policy for the management of radioactive waste: President Carter's message to Congress on February 12, 1980, and the 1979 report of the Interagency Review Group. This appendix contains the entire message and excerpts from the report.

C.1 PRESIDENT'S MESSAGE

On February 12, 1980, President Carter established a comprehensive program for the management of radioactive waste. His message to the Congress of the United States stated the objectives of that program and outlined the steps to be taken in carrying it out. The message specifically mentioned the WIPP project and the site near Carlsbad, New Mexico. The remainder of this section is a complete text of President Carter's message.

PRESIDENT CARTER'S MESSAGE TO CONGRESS

(February 12, 1980)

TO THE CONGRESS OF THE UNITED STATES:

Today I am establishing this Nation's first comprehensive radioactive waste management program. My paramount objective in managing nuclear wastes is to protect the health and safety of all Americans, both now and in the future. I share this responsibility with elected officials at all levels of our government. Our citizens have a deep concern that the beneficial uses of nuclear technology, including the generation of electricity, not be allowed to imperil public health or safety now or in the future.

For more than 30 years, radioactive wastes have been generated by programs for national defense, by the commercial nuclear power program, and by a variety of medical, industrial, and research activities. Yet, past governmental efforts to manage radioactive wastes have not been technically adequate. Moreover, they have failed to involve successfully the States, local governments, and the public in policy or program decisions. My actions today lay the foundation for both a technically superior program and a full cooperative Federal-State partnership to ensure public confidence in a waste management program.

My program is consistent with the broad consensus that has evolved from the efforts of the Interagency Review Group on Radioactive Waste Management (IRG) which I established. The IRG findings and analysis were comprehensive, thorough, and widely reviewed by public, industry and citizen groups, State and local governments, and members of the Congress. Evaluations of the scientific and technical analyses were obtained through a broad and rigorous peer review by the scientific community. The final recommendations benefited from and reflect this input.

My objective is to establish a comprehensive program for the management of all types of radioactive wastes. My policies and programs establish mechanisms to ensure that elected officials and the public fully participate in waste decisions, and direct Federal departments and agencies to implement a waste management strategy which is safe, technically sound, conservative, and open to continuous public review. This approach will help ensure that we will reach our objective--the safe storage and disposal of all forms of nuclear waste.

Our primary objective is to isolate existing and future radioactive waste from military and civilian activities from the biosphere and pose no significant threat to public health and safety. The responsibility for resolving military and civilian waste management problems shall not be deferred to future generations. The technical program must meet all relevant radiological protection criteria as well as all other applicable regulatory requirements. This effort must proceed regardless of future developments within the nuclear industry--its future size, and resolution of specific fuel cycle, and reactor design issues. The specific steps outlined below are each aimed at accomplishing this overall objective.

First, my Administration is committed to providing an effective role for State and local governments in the development and implementation of our nuclear waste management program. I am therefore taking the following actions:

- By Executive Order, I am establishing a State Planning Council which will strengthen our intergovernmental relationships and help fulfill our joint responsibility to protect public health and safety in radioactive waste matters. I have asked Governor Riley of South Carolina to serve as Chairman of the Council. The Council will have a total of 19 members: 15 who are Governors or other elected officials, and 4 from the Executive departments and agencies. It will advise the Executive Branch and work with the Congress to address radioactive waste management issues, such as planning and siting, construction, and operation of facilities. I will submit legislation during this session to make the Council permanent.

- In the past, States have not played an adequate part in the waste management planning process--for example, in the evaluation and location of potential waste disposal sites. The States need better access to information and expanded opportunity to guide waste management planning. Our relationship with the States will be based on the principle of consultation and concurrence in the siting of high level waste repositories. Under the framework of consultation and concurrence, a host State will have a continuing role in Federal decisionmaking on the siting, design, and construction of a high level waste repository. State consultation and concurrence, however, will lead to an acceptable solution to our waste disposal problem only if all the States participate as partners in the program I am putting forth. The safe disposal of radioactive waste, defense and commercial, is a national, not just a Federal, responsibility.

- I am directing the Secretary of Energy to provide financial and technical assistance to States and other jurisdictions to facilitate the full participation of State and local government in review and licensing proceedings.

Second, for disposal of high level radioactive waste, I am adopting an interim planning strategy focused on the use of mined geologic repositories capable of accepting both waste from reprocessing and unreprocessed commercial spent fuel. An interim strategy is needed since final decisions on many steps which need to be taken should be preceded by a full environmental review under the National Environmental Policy Act. In its search for suitable sites for high level waste repositories, the Department of Energy has mounted an expanded and diversified program of geologic investigations that recognizes the importance of the interaction among geologic setting, repository host rock, waste form, and other engineered barriers on a site-specific basis. Immediate attention will focus on research and development, and on locating and characterizing a number of potential repository sites in a variety of different geologic environments with diverse rock types. When four to five sites have been evaluated and found potentially suitable, one or more will be selected for further development as a licensed full-scale repository.

It is important to stress the following two points: First, because the suitability of a geologic disposal site can be verified only through detailed and time-consuming site specific evaluations, actual sites and their geologic environments must be carefully examined. Second, the development of a repository will proceed in a careful step-by-step manner. Experience and information gained at each phase will be reviewed and evaluated to determine if there is sufficient knowledge to proceed with the next stage of development. We should be ready to select the site for the first full-scale repository by about 1985 and have it operational by the mid-1990's. For reasons of economy, the first and subsequent repositories should accept both defense and commercial wastes.

Consistent with my decision to expand and diversify the Department of Energy's program of geologic investigation before selecting a specific site for repository development, I have decided that the Waste Isolation Pilot Plant project should be cancelled. This project is currently authorized for the unlicensed disposal of transuranic waste from our National defense program, and for research and development using high level defense waste. This project is inconsistent with my policy that all repositories for highly radioactive waste be licensed, and that they accept both defense and commercial wastes.

The site near Carlsbad, New Mexico, which was being considered for this project, will continue to be evaluated along with other sites in other parts of the country. If qualified, it will be reserved as one of several candidate sites for possible use as a licensed repository for defense and commercial high level wastes. My fiscal year 1981 budget contains funds in the commercial nuclear waste program for protection and continued investigation of the Carlsbad site. Finally, it is important that we take the time to compare the New Mexico site with other sites now under evaluation for the first waste repository.

Over the next five years, the Department of Energy will carry out an aggressive program of scientific and technical investigations to support waste solidification, packaging, and repository design and construction including several experimental, retrievable emplacements in test facilities. This supporting research and development program will call upon the knowledge and experience of the Nation's very best people in science, engineering, and other fields of learning, and will include participation of universities, industry, and the government departments, agencies, and national laboratories.

Third, during the interim period before a disposal facility is available, waste must and will continue to be cared for safely. Management of defense waste is a Federal responsibility; the Department of Energy will ensure close and meticulous control over defense waste facilities which are vital to our national security. I am committed to maintaining safe interim storage of these wastes as long as necessary and to making adequate funding available for that purpose. We will also proceed with research and development at the various defense sites that will lead the processing, packaging, and ultimate transfer to a permanent repository of the high level and transuranic wastes from defense programs.

In contrast, storage of commercial spent fuel is primarily a responsibility of the utilities. I want to stress that interim spent fuel storage capacity is not an alternative to permanent disposal. However, adequate storage is necessary until repositories are available. I urge the utility industry to continue to take all actions necessary to store spent fuel in a manner that will protect the public and ensure efficient and safe operation of power reactors. However, a limited amount of government storage capacity would provide flexibility to our national waste disposal program and an alternative for those utilities which are unable to expand their storage capabilities.

I reiterate the need for early enactment of my proposed spent nuclear fuel legislation. This proposal would authorize the Department of Energy to: (1) design, acquire or construct, and operate one or more away-from-reactor storage facilities, and (2) accept for storage, until permanent disposal facilities are available, domestic spent fuel, and a limited amount of foreign spent fuel in cases when such action would further our non-proliferation policy objectives. All costs of storage, including the cost of locating, constructing, and operating permanent geologic repositories, will be recovered through fees paid by utilities and other users of the services and will ultimately be borne by those who benefit from the activities generating the wastes.

Fourth, I have directed the Department of Energy to work jointly with states, other government agencies, industry and other organizations, and the public, in developing national plans to establish regional disposal sites for commercial low level waste. We must work together to resolve the serious near-term problem of low level waste disposal. While this task is not inherently difficult from the standpoint of safety, it requires better planning and coordination. I endorse the actions being taken by the Nation's governors to tackle this problem and direct the Secretary of Energy to work with them in support of their effort.

Fifth, the Federal programs for regulating radioactive waste storage, transportation, and disposal are a crucial component of our efforts to ensure the health and safety of Americans. Although the existing authorities and structures are basically sound, improvements must be made in several areas. The current authority of the Nuclear Regulatory Commission to license the disposal of high level waste and low level waste in commercial facilities should be extended to include spent fuel storage, and disposal of transuranic waste and non-defense low level waste in any new government facilities. I am directing the Environmental Protection Agency to consult with the Nuclear Regulatory Commission to resolve issues of overlapping jurisdiction and phasing of regulatory actions. They should also seek ways to speed up the promulgation of their safety regulations. I am also directing the Department of Transportation and the Environmental Protection Agency to improve both the efficiency of their regulatory activities and their relationships with other Federal agencies and state and local governments.

Sixth, it is essential that all aspects of the waste management program be conducted with the fullest possible disclosure to and participation by the public and the technical community. I am directing the departments and agencies to develop and improve mechanisms to ensure such participation and public involvement consistent with the need to protect national security information. The waste management program will be carried out in full compliance with the National Environmental Policy Act.

Seventh, because nuclear waste management is a problem shared by many other countries and decisions on waste management alternatives have nuclear proliferation implications, I will continue to encourage and support bilateral and multilateral efforts which advance both our technical capabilities and our understanding of spent fuel and waste management options, which are consistent with our non-proliferation policy.

In its role as lead agency for the management and disposal of radioactive wastes and with cooperation of the other relevant Federal agencies, the Department of Energy is preparing a detailed National Plan for Nuclear Waste Management to implement these policy guidelines and other recommendations of the IRG. This Plan will provide a clear road map for all parties and will give the public an opportunity to review the entirety of our program. It will include specific program goals and milestones for all aspects of nuclear waste management. A draft of the comprehensive National Plan will be distributed by the Secretary of Energy later this year for public and Congressional review. The State Planning Council will be directly involved in the development of this Plan.

The Nuclear Regulatory Commission now has underway an important proceeding to provide the Nation with its judgment on whether or not it has confidence that radioactive wastes produced by nuclear power reactors can and will be disposed of safely. I urge that the Nuclear Regulatory Commission do so in a thorough and timely manner and that it provide a full opportunity for public, technical, and government agency participation.

Over the past two years as I have reviewed various aspects of the radioactive waste problem, the complexities and difficulties of the issues have become evident--both from a technical and, more importantly, from an institutional and political perspective. However, based on the technical conclusions reached by the IRG, I am persuaded that the capability now exists to characterize and evaluate a number of geologic environments for use as repositories built with conventional mining technology. We have already made substantial progress and changes in our programs. With this comprehensive policy and its implementation through the FY 1981 budget and other actions, we will complete the task of reorienting our efforts in the right direction. Many citizens know and all must understand that this problem will be with us for many years. We must proceed steadily and with determination to resolve the remaining technical issues while ensuring full public participation and maintaining the full cooperation of all levels of government. We will act surely and without delay, but we will not compromise our technical or scientific standards out of haste. I look forward to working with the Congress and the states to implement this policy and build public confidence in the ability of the government to do what is required in this area to protect the health and safety of our citizens.

JIMMY CARTER

THE WHITE HOUSE

C.2 FINDINGS AND RECOMMENDATIONS OF THE INTERAGENCY REVIEW GROUP ON NUCLEAR WASTE MANAGEMENT

An important document in the development of the national waste-management program has been the report of the Interagency Review Group on Nuclear Waste Management (IRG, 1979). After a brief review of the purpose of this Group and its major technical findings, this section presents quotations taken from two parts of the Group's report: the sections dealing with the disposal of transuranic (TRU) waste and with the disposal of high-level waste (HLW). Although high-level waste would not be disposed of at the WIPP, the quotations dealing with high-level waste are included here as reference material supporting the discussion of alternatives in Chapters 3 and 4.

The Interagency Review Group was formed in order to guide the national waste-management program. President Carter called for a review of the waste-management program in his April 1977 National Energy Plan. In response to this request, the DOE established an internal task force and published a draft report in March 1978. The President then created the formal Interagency Review Group on Nuclear Waste Management and instructed it to make policy and program recommendations to him, using the draft report of the DOE task force as one input. This group, chaired by the DOE, comprised representatives of 14 agencies. It developed a draft report to the President that was published for public comment in October 1978 (IRG, 1978). After the review of public comment, the Interagency Review Group published a revised report (IRG, 1979).

The Interagency Review Group consulted extensively with the scientific and technical community, including independent geologic and environmental experts. The Group's summary of the major technical findings of this activity (IRG, 1979, p. 42) is quoted in full below.

> Present scientific and technological knowledge is adequate to identify potential repository sites for further investigation. No scientific or technical reason is known that would prevent identifying a site that is suitable for a repository provided that the system's view is utilized rigorously to evaluate the suitability of sites and designs, and in minimizing the influence of future human activities. A suitable site is one at which a repository would meet predetermined criteria and which would provide a high degree of assurance that radioactive waste can be successfully isolated from the biosphere for periods of thousands of years. For periods beyond a few thousand years, our capability to assess the performance of the repository diminishes and the degree of assurance is therefore reduced. The feasibility of safely disposing of high-level waste in mined repositories can only be assessed on the basis of specific investigations at and determinations of suitability of particular sites. Information obtained at each successive step of site selection and repository development will permit reevaluation of risks, uncertainties, and the ability of the site and repository to meet regulatory standards. Such reevaluations would lead either to abandonment of the site or a decision to proceed to the next step. Reliance on conservative engineering practices and multiple independent barriers can reduce some risks and compensate for some uncertainties. However, even at the time of decommissioning, some uncertainty about repository performance will still exist. Thus, in addition to technical evaluation, a societal judgment that considers the level of risk and the associated uncertainty will be necessary.

IRG Discussion of a Generic Approach to TRU-Waste Disposal

The Interagency Review Group raised an important issue about TRU waste disposal: should a dedicated TRU-waste repository be built if an opportunity exists to do so, or should TRU-waste disposal await the availability of high-level-waste repositories and take place there? The IRG report states (IRG, 1979, p. 73) that "the IRG still considers that proceeding with a dedicated TRU repository, if an opportunity is available, is consistent with a conservative and stepwise approach."

It should be noted, however, that the Interagency Review Group approached this question generically, as an appropriate interim strategic-planning basis until the environmental-review provisions of the National Environmental Policy Act (NEPA) have been carried out. The discussion by the Interagency Review Group (IRG, 1979, pp. 69-70) of strategies for TRU-waste disposal is reproduced in full below.

> As with choosing a strategy for HLW disposal, the choice of a TRU waste disposal strategy must await completion of an appropriate environmental impact statement and its adoption through the NEPA process. In the meantime, Federal actions regarding the management of TRU waste must not prejudice the choice of strategies for their disposal. Nevertheless, an interim strategic planning basis will be necessary to guide the TRU-waste management programs and R&D activities before that choice is made.
>
> In laying out the following technical strategies for TRU waste disposal, the IRG assumed that all TRU waste, whether generated by commercial or defense operations, would be disposed of in the same manner because no technical reason exists to treat them differently. The two strategies examined by the IRG are:
>
> <u>Strategy 1</u>. No special action would be taken to pursue TRU waste disposal prior to the opening of a high-level-waste repository. TRU waste would be disposed of in high-level-waste repositories whenever they become available.
>
> <u>Strategy 2</u>. If an opportunity can be found, the program would proceed with an early dedicated TRU repository as soon as a site could be appropriately qualified and NEPA requirements fulfilled.
>
> Enough TRU waste now exists stored above ground to warrant the opening of a repository dedicated to TRU. Such a facility could probably hold all the TRU waste to be generated through the end of this century. Of course, once a high-level-waste repository were available, decisions on the location for disposal of then existing TRU wastes could be made on a case by case basis to maximize convenience and minimize transportation. A second repository dedicated to TRU waste alone would seem to be unnecessary.
>
> Because of the presence in TRU waste of substantial quantities of transuranic radionuclides, issues related to long-term containment (such as the potential for groundwater transport, any possibilities of repository breachment, and concerns about mineral resources or tectonism) are identical for TRU and HLW repositories. However, the problems associated with heat generation and increases in temperature are absent and the TRU wastes are not as difficult to handle as HLW. The operational demands on a disposal system designed for TRU waste alone would be more modest than those associated with a HLW repository. In addition, because of the absence of heat-related considerations, the regulatory review of a dedicated TRU repository would be somewhat simplified compared with that for a HLW repository.
>
> Proceeding with an early, dedicated TRU repository would therefore be consistent with the previously recommended philosophy of [conservatism] and proceeding stepwise into the most difficult disposal problem and would signal the government's determination to proceed in a timely manner with disposal of nuclear wastes. There would, of course, be some additional costs associated with the opening of a dedicated TRU facility.
>
> <u>Having considered these various matters, the IRG recommends adopting, as an interim strategic planning basis pending NEPA review, the concept of proceeding with an early TRU repository if an opportunity exists to do so.</u>

IRG Discussion of High-Level-Waste Disposal

The Interagency Review Group defined four technical strategies for high-level-waste disposal (IRG, 1979, pp. 49-50):

- Strategy I provides that only mined repositories would be considered and that only geological environments with salt as the emplacement media would be considered for the first several repositories. As a result of past focusing on salt, there is a large volume of information available. In addition, one body of opinion holds that salt is the best, or at least an acceptable, emplacement medium and that suitable sites can be found where salt is the host rock.

- Strategy II provides that, for the first few facilities, only mined repositories would be considered. A choice of site for the first repository would be made from among whatever types of environments have been adequately characterized at the time of choice. Because generic understanding of engineering features of a salt repository are most advanced, the first choice is expected to be made from environments based on salt geology. Sites from a wider range of geologic environments would be available for selection somewhat later.

- Strategy III provides that, for the first facility only mined repositories would be considered. However, three to five geological environments possessing a wide variety of emplacement media would be examined before a selection was made. Other technological options would be contenders as soon as they had been shown to be technologically sound and economically feasible.

- Strategy IV provides that the choice of technical options and, if appropriate, geological environment be made only after information about a number of environments and other technical options has been obtained.

These strategies were intended to illustrate the range of possible strategic approaches. They were not intended to be a complete list of possible strategies or comprehensive descriptions of a strategic planning basis that might actually be adopted by the waste disposal program. For the latter purpose, they are admittedly incomplete.

IRG Discussion of Key Elements of Interim Strategic-Planning Basis for High-Level Waste

As a result of comments on its draft report, the IRG (1979, pp. 61-62) expanded and clarified its views on the interim strategic-planning basis for high-level waste, restating them as follows:

- The approach to permanent disposal of nuclear waste should proceed on a stepwise basis in a technically conservative manner....

- Near-term R&D and site characterization programs should be designed so that at the earliest date feasible, sites selected for location of a repository can be chosen from among a set with a variety of potential host rock and geohydrological characteristics. To accomplish this, R&D on several potential emplacement media and site characterization work on a variety of geologic environments should be increased promptly.

- A number of potential sites in a variety of geologic environments should be identified and early action should be taken to reserve the option to use them if needed at an appropriate time. In order to avoid working toward and ultimately having a single national repository, near-term options should create the option to have at least two (and possibly three) repositories become operational within this century, ideally and insofar as technical considerations permit, in different regions of the country. In pursuing a regional approach to siting, geologic, hydrologic, tectonic and other technical characteristics of sites must remain the primary basis for selection.

- Construction and operation of a repository should proceed on a stepwise basis and initial emplacement of waste in at least the first repository should be planned to proceed on a technically conservative basis and permit retrievability of the waste for some initial period of time. Further definition of the retrievability concept, the circumstances in which waste would be retrieved and the technical aspects (including development of waste packaging, containers and handling) is necessary.

All IRG members agreed with the above elements of the recommended interim strategic-planning basis for high-level waste. They asserted further (IRG, 1979, p. 33) that these elements

- do not prejudge the NEPA process
- require the Federal government to maintain a technically conservative approach
- call for resolution of uncertainties by increasing the technical and program breadth with respect to the near-term repository characterization program
- do not preclude subsequent adoption of longer term technologies inasmuch as they call for increased R&D to develop selected alternatives
- support a step-wise approach to the development of a HLW repository, while maintaining storage capacity for managing wastes until emplacement and disposal opportunities are available

The IRG did not come to a consensus on the basis for selecting the site for the first high-level-waste repository.

REFERENCES

IRG (Interagency Review Group), 1978. Report to the President by the Interagency Review Group on Nuclear Waste Management (draft), TID-28817, U.S. Department of Energy, Washington, D.C.

IRG (Interagency Review Group), 1979. Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-29442, U.S. Department of Energy, Washington, D.C.

Appendix D

SELECTION CRITERIA FOR THE WIPP SITE

CONTENTS

Appendix D

SELECTION CRITERIA FOR THE WIPP SITE

This appendix briefly describes how the geologic, hydrologic, and other characteristics of the WIPP site in southeastern New Mexico meet site-selection criteria and factors. The criteria and factors given here are from the Geological Characterization Report (Powers et al., 1978, pp. 2-15ff) and are based on criteria suggested earlier by the Oak Ridge National Laboratory (ORNL, 1973), the International Atomic Energy Agency (1977), and Brunton and McClain (1977).

The site-selection criteria described here were originally formulated under the expectation that the WIPP would be a repository that would contain spent fuel from nuclear reactors. The heat emitted by spent fuel would have had important effects on the salt in which it was emplaced; for that reason, some of the criteria were specifically intended to insure the safety of spent-fuel emplacement. The WIPP mission no longer includes the disposal of spent fuel or any other high-level waste. Furthermore, the design of the WIPP no longer includes the separate mined cavity for high-level waste called the "lower repository" or the "lower horizon" in the criteria. Accordingly, not all the criteria presented here are applicable to the WIPP under its current mission and design. Because the site was, however, actually selected under these criteria, no effort has been made to revise them for this document.

D.1 GEOLOGIC CRITERION AND SITE-SELECTION FACTORS

The geology of the site will be such that the repository will not be breached by natural phenomena while the waste poses a significant hazard to man. The geology must also permit safe operation of the WIPP repository.

Topography. The terrain must permit access for transportation. The effect on inducing salt flow during excavation must be considered. Surface-water flow and the potential for flooding must be evaluated.

The maximum relief over the WIPP repository is 120 feet. The regional relief is low and easily accommodates the required transportation corridors. The location near a broad surface and groundwater divide will minimize the development of future relief. Differential stress in the salt due to surface relief is not a significant factor in causing deformation in the salt. (See Powers et al., 1978, Sections 3.2 and 4.2.)

Depth. Repository horizons should be deeper than 1000 feet to insure that erosion and consequences of surficial phenomena are not a major concern. The depth of suitable horizons will not exceed 3000 feet to limit the rate of salt deformation around the excavations.

The selected repository bed for heat-producing waste varies between depths of 2750 and 2250 feet over the potential excavation area. The bed for TRU waste ranges from 2200 to 1800 feet deep through the repository region. These depths are based on interpretations of seismic reflection data. (See Powers et al., 1978, Sections 3.3, 4.3, and 9.2.)

Thickness. The total thickness of the salt deposits should be several hundred feet to buffer thermal and mechanical effects. The desired thickness for the repository bed is 20 feet or more to mitigate the thermal and mechanical effects at nonhalite units.

The halite unit in which the heat-producing waste will be placed is about 100 feet thick. The total thickness of the evaporite section provides about a 1300-foot buffer above and below the repository horizons. This distance to the nearest potential aquifers insures that the thermal effects at these aquifers will be insignificant. (See Powers et al., 1978, Sections 4.3.2 and 9.2.)

Lateral extent. The distance to structural or dissolution boundaries must be adequate to provide for future site integrity. For the Los Medanos area a distance of 5 miles to the Capitan reef and 1 mile to regional Salado dissolution has been established.

From seismic data and drill-hole information, the selected horizons are believed to extend well beyond the repository site. The separations from the deformed salt belt parallel to the Capitan reef and from the natural dissolution fronts are adequate to insure the required site integrity. (See Powers et al., 1978, Sections 3.3, 4.3, and 6.3.)

Lithology. Purity of the salt beds is desirable. Brine in the salt could induce geochemical interactions; pending further investigations, 3% brine is established as a desirable upper limit for the heat-producing waste horizon. Additional geochemical interactions must be considered if significant chemical or mineral impurities are present.

The horizon within the lower Salado that will accommodate the heat-producing wastes averages more than 97% halite from the samples analyzed. Brine content averages less than 0.5%. (See Powers et al., 1978, Sections 4.3 and 7.2 through 7.6.)

Stratigraphy. Continuity of beds, character of interbedding, and nature of beds overlying and underlying the salt are important considerations in the construction of the facility; they are also important in insuring the long-term integrity of the repository.

There are no beds of clay or polyhalite near enough to the lower repository horizon to affect repository construction and operation or to affect the long-term performance of the repository. The significant nonhalite beds adjacent to the heat-producing-waste horizons are principally anhydrite, which has favorable thermal, mechanical, and chemical properties for bounding layers. The upper (TRU-waste) level of the repository can also be located to avoid rock-mechanics instabilities due to interbeds of nonhalite rock. (See Powers et al., 1978, Sections 3.3, 3.4, 4.3, and 4.4.)

Structure. Relatively flat bedding (less than 3 degrees) is desirable for operational purposes. Steep anticlines and major faults are to be avoided.

Seismic-reflection data and drill-hole information have been interpreted as showing relatively flat (less than 1 degree) bedding over most of the 3-square-mile repository horizon. Seismic data do show a small anticline at the northern edge of control zone II. Drilling on this anticline (WIPP-12) has shown that the elevation difference of the repository beds, from ERDA-9 at the center of the repository to WIPP-12, is less than 200 feet, an average of about 2 degrees. Photography, satellite imagery, surface mapping, geophysical techniques, and drilling have been used to search for indications of significant faulting. No post-Permian faults are known to exist in the site area. Seismic indications of faulting in older, deeper rocks do not extend through the Permian evaporite section.

The lack of severe structure and recent faulting satisfactorily meets the desired conditions for this factor. (See Powers et al., 1978, Sections 3.4 and 4.4.)

Erosion. While the depth of the repository reduces concern about erosion, it is desirable to avoid features that would tend to localize or accelerate erosion.

The site is located near a broad surface-water divide, and the local base level is at an elevation of about 2900 feet. Consequently, future erosion will proceed less rapidly over the site than in the established drainage channels. The expected erosion rates will not expose the Salado salt within the required lifetime of the repository. Future climatic changes will not alter this assessment, and glaciation is not expected to be a concern at this location. (See Powers et al., 1978, Sections 3.2.3, 3.6, 4.2, and 6.2.)

Dissolution. Regional and/or local dissolution must not breach the repository while the wastes represent a significant hazard to people. While there are various suggestions for the time a repository should remain isolated from the biosphere, a period of 250,000 years (10 half-lives of plutonium-239) is commonly used to represent the time over which the wastes are significantly hazardous.

Studies by the U.S. Geological Survey indicate that the maximum rate of horizontal progression of the salt-dissolution front in Nash Draw, averaged over the past 500,000 years, has been 6 to 8 miles per million years and less than 500 feet vertically per million years. The nearest active solution front is to the west, in Nash Draw. This is far enough from the site to provide repository isolation for more than 2 million years. (See Powers et al., 1978, Section 6.3.6.)

Subsidence. Subsidence due to dissolution of salt will be avoided when the subsidence adversely affects the repository beds or unduly accelerates the rate of dissolution to the jeopardy of the long-term integrity of the repository.

Subsidence has occurred over the western portion of the WIPP site area because of the natural removal of salt from the Rustler Formation. Hydrologic data from this region indicate that the major aquifers in the Rustler have different potential heads, and thus this regional subsidence has not caused them to be interconnected by permeable fractures. No sinks due to localized solutioning are present at the site.

D.2 HYDROLOGIC CRITERION AND SITE-SELECTION FACTORS

The hydrology of the site must provide high confidence that natural dissolution will not breach the site while the waste poses a significant hazard to man. Accidental penetrations should not result in undue hazards to mankind.

Surface water. Present and future runoff patterns, flooding potential, etc., should not endanger the penetrations into the repository while these openings are unplugged.

Because the site is near a broad surface-water divide, lacks established drainage, and is well above the Pecos River, simple construction techniques will prevent flooding of the repository. (See Powers et al., 1978, Section 6.2.)

Aquifers. For the WIPP, the overlying and underlying aquifers represent a secondary barrier if the salt is breached. Consequently, low permeability and transmissivity are desirable but not mandatory. Accurate knowledge of aquifer parameters is important to construction, decommissioning, and realistic calculation of the consequences of failure scenarios.

Aquifers above and below the repository have low transmissivity. Consequently, flooding of the repository during its operation through shafts or drill holes is not credible. These access points can readily be plugged to prevent water inflow after decommissioning.

The quantity of water carried by the major aquifers above and below the WIPP beds is too small to be useful. Furthermore, the water carries too many salts to be potable or otherwise useful.

The hydrologic parameters of the aquifers do not permit rapid flow of water. The low permeability would limit the flow even if heads were to be modified in future pluvial cycles. (See Powers et al., 1978, Section 6.3.)

Hydrologic transport. For the WIPP, this is a secondary factor that must be evaluated to allow quantitative calculations of the consequences of various failure scenarios. Slow transport of isotopes is acceptable if more critical factors have been satisfied.

Calculations based on various postulated failure scenarios show that the transport of radionuclides through the overlying and underlying aquifers would be so slow that a significant hazard to people would not exist even if the salt beds were breached. The nearest natural discharge point is near Malaga Bend on the Pecos River, over 14 miles away. At the maximum measured rate of water movement, it would take about 1700 years after a breach for the first trace of nonretarded nuclides (i.e., iodine-129) to appear at the Pecos. The long-lived transuranic nuclides would be retarded by the sorption of ions and would not begin to appear at Malaga Bend until 35,000 years after a postulated breach of the salt beds. The concentrations of radionuclides (or possible radiation doses) would never reach significant hazard levels in the Pecos River. (See Powers et al., 1978, Sections 6.3, 9.3, and 10.6.)

Climatic fluctuations. Possible pluvial cycles must be considered in estimating the effects of the hydrologic factors.

The dissolution and erosion rates established as averages over the past 500,000 years include the effects of several past pluvial cycles. It is expected that future cycles would also be shorter than the isolation time sought for the repository. Transport rates under different climates (rainfall) can be estimated by appropriate boundary conditions on the hydrologic model. The low permeability of the major aquifers above the site will not be significantly altered by the climatic changes expected for this area, and the resultant flow in the aquifers will not be grossly altered by changed climatic conditions. (See Powers et al., 1978, Sections 3.6 and 4.5, Chapter 6, and Section 10.3.)

Man-made penetrations. The effect of drill holes and mining operations must be included in evaluating the potential effects of dissolution.

The repository and control zone III are free of preexisting boreholes that extend through the salt, shafts, and mining activity. Any existing or future holes in any of the WIPP zones must be adequately plugged when abandoned.

D.3 TECTONIC STABILITY CRITERION AND SITE-SELECTION FACTORS

Natural tectonic processes must not result in a breach of the site while the wastes represent a significant hazard to people and should not require extreme precautions during the operational period of the repository.

Seismic activity. The frequency and magnitude of seismic activity impact facility design and safety of operation. Low levels of seismicity are desirable, but facility design can accommodate higher levels as well.

The WIPP site is in an area of relatively low seismic activity. The nearest seismic activity has been 10 or more miles north of the site and of small magnitude. It is not known whether the three nearest events were tectonic, related to salt dissolution, or a result of human activity. No faulting has been observed in the area of these seismic events. In any case, they and the potential future events pose no hazard for a properly constructed repository and are no threat to its long-term integrity. (See Powers et al., 1978, Chapter 5 and Section 10.5.)

Faulting and fracturing. While open faults, fractures, or joints are not expected in salt, the more brittle units within and surrounding the salt may support such features that can enhance dissolution and hydrologic transport. Major faults and pronounced linear structural trends should be avoided.

No major structural trends of recent geologic age are known to exist in the site area. The nearest recent faulting observed is on the west side of the Guadalupe Mountains, some 70 miles away. Seismic-reflection data have indicated small faults in deep, old rocks below the Salado Formation. There are no known tectonic faults in post-Permian rocks at the site area. Thousands of miles of drift in the potash mines in the Salado salt have not encountered any open fractures or faults through which groundwater had penetrated.

Salt-flow anticlines. Major deformation of salt beds by flow can fracture brittle rock and create porosity for brine accumulations. Major anticlines resulting from salt flow should be avoided or evaluated to check on brine presence and anhydrite fracturing.

The only anticlines within the site are relatively minor features. Both have been drilled, however, and the cores show little fracturing or porosity and no accumulation of fluids. These small anticlines will not hinder repository construction or jeopardize its long-term safety. (See Powers et al., 1978, Section 4.4.)

Diapirism. An extreme result of salt flow, this feature will be avoided for WIPP siting.

There are no known or indicated diapirs (salt domes) at the WIPP site. (See Powers et al., 1978, Section 4.4.)

Regional stability. Areas of pronounced regional uplift or subsidence should be avoided since such behavior makes prediction of future dissolution, erosion, and salt flow more uncertain.

Geologic mapping has failed to reveal any indicators of regional instability. Caliche formation and attitude indicate stable conditions in the site region over the last half-million years. The lack of scarps and the natural seismicity are consistent with regional stability. (See Powers et al., 1978, Sections 3.4, 4.4, and 10.3.2.)

Igneous activity. Areas of active or recent volcanism or igneous intrusion should be avoided to minimize these hazards to the repository.

No recent igneous activity is known in the region. Geophysical surveys, mining, and drill-hole intercepts have shown that an intrusive dike exists 9 miles northwest of the site. Radiometric dating shows it to be 35 million years old. No other intrusive features are known to exist in the region. (See Powers et al., 1978, Section 3.5.)

Geothermal gradient. Abnormally high geothermal gradients should be avoided to allow construction in salt at 3000 feet. High gradients may also be indicative of recent igneous or tectonic activity.

The geothermal gradient as determined in the AEC-8 drill hole shows a normal geothermal gradient averaging about 0.58°F per 100 feet. The heat flow is about one heat-flow unit. (See Powers et al., 1978, Section 4.4.1.)

D.4 PHYSICOCHEMICAL COMPATIBILITY CRITERION AND SITE-SELECTION FACTORS

The repository medium must not interact with the waste in ways that create unacceptable operational or long-term hazards.

Fluid content. The repository bed containing high-level waste should not contain more than 3% brine. The limit for TRU waste has not been established, but the value used for high-level waste is acceptable.

The average brine content of the lower repository is less than 0.5% by weight. The average brine content of the upper repository horizon beds is less than 1% by weight. (See Powers et al., 1978, Sections 7.5 and 10.7.8.)

Thermal properties. To avoid undesirable temperature rises, no major natural thermal barriers should exist closer than 20 feet of the repository horizons.

This is of significance to the lower horizon, where the halite unit of interest is about 100 feet thick. The adjoining beds are anhydrite, which, even though far enough away, has similar thermal conductivity and does not represent a thermal barrier in any case. (See Powers et al., 1978, Section 9.2.3.)

Mechanical properties. The medium must safely support excavation of openings even while thermally loaded. Clay seams and zones of unusual structural weakness should be avoided in the selection of the repository horizon.

The halite bed at the lower level is sufficiently thick and devoid of clay seams that stability of openings will not be a problem for repository operation. Clay seams and polyhalite beds are more common in the area selected for the upper repository level, but construction levels can be located to avoid significant structural stability problems from such nonhalite beds. (See Powers et al., 1978, Section 9.2.4.)

Chemical properties and mineralogy. Beds that are of unusual composition or contain minerals with bound water should not occur within 20 feet of the waste horizon. This will lessen the uncertainties with regard to thermally driven geochemical interactions.

The heat-producing waste horizon is quite pure halite, with more than 97% NaCl. No polyhalite, clay, or other water-bearing minerals occur near this horizon. The upper horizon beds are more than 92% NaCl, with impurities being mostly potassium and magnesium salts and clay. These impurities have no known negative implications for TRU-waste isolation and, in fact, have been shown to absorb radionuclides from brine. (See Powers et al., 1978, Sections 4.3 and 7.2 through 7.5.)

Radiation effects. While no unacceptably deleterious effects are postulated, these phenomena are best quantified in halite, and thus the purer rock salt beds are desired for high-level waste.

Samples of WIPP salt show no characteristics that would produce undesirable effects under irradiation. The low brine content will limit the amount and effects of radiolytic disassociation of water. (See Powers et al., 1978, Chapter 9.)

Permeability. Salt has a very low permeability. It is necessary to evaluate the permeability only of the interbeds and the surrounding media. Low permeability is desirable, but quantitative limits need not be specified for site selection. Salt permeability to gases may be important in establishing waste-acceptance criteria.

Laboratory measurements on cores show very low permeability. On a large scale, measurements at the WIPP horizons have not been made. Experience in other drill holes (absence of aquifers in salt and presence of small high-pressure gas pockets) would argue for very low in-situ permeability on larger scales. (See Powers et al., 1978, Section 9.2.3.)

Nuclide mobility. This is a secondary factor in siting since confinement by the salt and isolation from water are the basic isolation premises. Ion sorption must be determined to allow quantification of safety analyses and to indicate whether engineered barriers (clay) would be beneficial.

The distributed impurities in the rock salt provide significant ion-sorption capability for many radionuclides. The clay layers in higher salt beds will be still more sorptive. These properties will tend to minimize radionuclide migration due to such local mechanisms as brine migration in thermal gradients. (See Powers et al., 1978, Section 9.3.)

D.5 ECONOMIC AND SOCIAL COMPATIBILITY CRITERION AND SITE-SELECTION FACTORS

The site must be operable at reasonable economic cost and should not create unacceptable impacts on natural resources or the biological and social environment.

Natural resources. Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible.

This factor is not well satisfied by the WIPP site. Both hydrocarbons and potash exist in potentially economic quantities within the site. While salt itself may be considered a valuable mineral, its economic potential at the site is very low. Since both potash and hydrocarbons may be recovered from control zone IV, the amounts that may be restricted from development within zones I, II, and III are the critical amounts. These quantities are not large in terms of national supply (even the langbeinite product is synthesized in quantity from brine lakes). These minerals may prove an enticement for future exploration and exploitation. For this reason, studies are under way to examine the effects of recovering the potash ore from above control zone III. Very little potash exists above the repository (zone II) itself. Similarly, once adequate borehole plugging is demonstrated, drilling in zone III could be permitted or the same zones developed from zone IV by slant drilling. The expectation, but one that cannot yet be guaranteed, is that these minerals may be recovered in the decades ahead should they be economically attractive. Certainly the time frame for their development would be within the next century, while the site is still under administrative control. The small amounts of either resource within zone III would not be of significant interest in the absence of other production in the area. (See Powers et al., 1978, Chapter 8.)

Man-made penetrations. Boreholes or shafts that penetrate through the salt into underlying aquifers will be avoided within 1 mile of the repository. Existing mining activity, unrelated to the repository, should not be present within 2 miles of the repository. Future, controlled mining will be allowable up to 1 mile from the repository. Future studies may permit still closer mining and drilling if properly controlled.

The present site adequately fulfills this present restriction on man-made penetrations. (See Powers et al., 1978, Section 2.3 and Chapter 4.)

Transportation. Transportation should be capable of ready development. Avoidance of population centers by transportation routes is not a factor in the siting of the repository.

The present site meets this requirement and would utilize a spur line of the Santa Fe Railroad now running to the Duval mine.

Accessibility. The site should be readily accessible for transportation and utilities.

The site presents no problems for access by road, railroad, or utility lines.

Land jurisdiction. Siting will be on Federal land to the extent possible.

Of the 18,960 acres to be withdrawn by the DOE if this site is approved, 17,200 are Federal land controlled by the Bureau of Land Management and 1760 acres belong to the State of New Mexico. There are no private lands within the site.

Population density. Proximity to population centers and rural habitats will be considered in siting. A low population density in the immediate site area is desirable.

There are 16 permanent residents within 10 miles of the site. There is a transient population at potash mines. The nearest town is Loving, New Mexico, with a population of 1600. Carlsbad is 26 miles west and has a population of 28,600. Low population is not necessary to siting but, all other factors being equal, is desirable.

Effects on ecology and cultural resources. Major impacts on ecology due to construction and operation should not occur. Archaeological and historic features of significance should be preserved.

No major or unusual impacts on the environment or the ecologic system are expected from the construction and the operation of the repository. No endangered species of plants or animals are known to occur at the site. No significant archaeological sites will be destroyed by repository construction.

Sociological impacts. Demographic and economic effects should not result in unacceptable sociological impacts.

There was no a priori reason to expect any severe or unacceptable socioeconomic impacts attributable to the site location. This assessment has been substantiated by the socioeconomic studies reported in Section 9.4 of this document.

REFERENCES

Brunton, G. D., and W. C. McClain, 1977. Geological Criteria for Radioactive Waste Repositories, Y/OWI/TM-47, Office of Waste Isolation, Union Carbide Corporation, Oak Ridge, Tenn.

International Atomic Energy Agency, 1977. Site Selection Factors for Repositories of Solid High-Level and Alpha-Bearing Waste in Geological Formations, Technical Report Series No. 177, Vienna, Austria.

Oak Ridge National Laboratory (ORNL), 1973. Site Selection Factors for the Bedded Salt Pilot Plant, ORNL-TM-4219, Oak Ridge, Tenn.

Powers, D. W., S. J. Lambert, S.-E. Shaffer, L. R. Hill, and W. D. Weart (eds.), 1978. Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico, two volumes, SAND78-1596, Sandia Laboratories, Albuquerque, N.M.