ORNL/TM-12940

OAK RIDGE NATIONAL LABORATORY

LOCKHEED MARTIN



# THE SITING RECORD:

## An Account of the Programs of Federal Agencies and Events That Have Led to the Selection of a Potential Site for a Geologic Repository for High-Level Radioactive Waste

T. F. Lomenick



MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

ORNL/TM-12940

Chemical Technology Division

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March 1996

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operated by
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for the
U.S. Department of Energy
under
Contract No. DE-AC05-96OR22464

*Retired October 1, 1994.

# CONTENTS

## List of Figures

# List of Tables

## Acronyms and Abbreviations

| | |
|---|---|
| AAPG | American Association of Petroleum Geologists |
| AASG | American Association of State Geologist |
| AEA | Atomic Energy Act of 1954 |
| AEC | Atomic Energy Commission |
| API | American Petroleum Institute |
| ARHCO | Atlantic Richfield Hanford Company |
| ARR | Area Recommendation Report |
| BWIP | Basalt Waste Isolation Project |
| C&C | consultation and cooperation |
| DOE | Department of Energy |
| EA | Environmental Assessment |
| EIS | environmental impact statement |
| EPA | U.S. Environmental Protection Agency |
| EPM | Environmental Project Manager |
| ERDA | Energy Research and Development Administration |
| ES | exploratory shaft |
| FRG | Federal Republic of Germany |
| GDEP | Geologic Disposal Evaluation Program |
| GPM | Geologic Project Manager |
| GRG | Geologic Review Group |
| HLW | high-level waste |
| IAEA | International Atomic Energy Agency |
| IEA | International Energy Agency |
| IHWG | Interagency Hydrology Working Group |
| IRG | Interagency Review Group |
| KGS | Kansas Geological Survey |
| LASL | Los Alamos Scientific Laboratory |
| LBNL | Lawrence Berkeley National Laboratory |
| LLNL | Lawrence Livermore National Laboratory |
| LLW | low-level waste |
| LSU | Louisiana State University |
| MRS | Monitored Retrievable Storage |
| NAS | National Academy of Sciences |
| NEA | Nuclear Energy Agency |
| NEPA | National Environmental Policy Act |
| NNWSI | Nevada Nuclear Waste Storage Investigation |
| NRC | U.S. Nuclear Regulatory Commission |
| NRDA | Nevada Research and Development Area |
| NRDC | Natural Resources Defense Council |
| NTS | Nevada Test Site |
| NVO | Nevada Operations Office |
| NWPA | Nuclear Waste Policy Act of 1982 |
| NWPAA | Nuclear Waste Policy Act Amendments |
| NWTS | National Waste Terminal Storage |
| OCRD | Office of Crystalline Repository Development |
| OCRWM | Office of Civilian Radioactive Management |

| | |
|---|---|
| ONWI | Office of Nuclear Waste Isolation |
| ORNL | Oak Ridge National Laboratory |
| OWI | Office of Waste Isolation |
| QA | quality assurance |
| R&D | research and development |
| RGCR | regional geologic characterization reports |
| RHO | Rockwell Hanford Operations |
| RRL | Reference Repository Location |
| RSSF | Retrievable Surface Storage Facility |
| SCP | Site Characterization Plan |
| SNL | Sandia National Laboratory |
| SWEC | Stone and Webster Engineering Corporation |
| TBEG | Texas Bureau of Economic Geology |
| TEF | Test and Evaluation Facility |
| TRU | transuranic |
| UKCR | University of Kansas Center for Research |
| USGS | U.S. Geological Survey |
| WIPP | Waste Isolation Pilot Plant |
| YM | Yucca Mountain |

# FOREWORD AND ACKNOWLEDGMENTS

The U.S. Department of Energy (DOE) has prepared this Siting Record to provide an account of the process of siting a geologic repository for high-level radioactive waste from the inception of this concept in 1950 to 1987 when Yucca Mountain (YM), Nevada was designated as the single site to undergo detailed geologic characterization. We believe that the material contained in this record will be useful to future policy makers and serve as a reference document for interested readers. We also believe that this record will clarify issues and events affecting siting that might otherwise become obscured. Without doubt, the siting and construction of a disposal facility for high-level radioactive waste is one of the most complex problems to face our country in this century. This is due in part to the unprecedented nature of the technical aspects of the problem which impose a necessity to contain the waste materials for thousands of years. However, perhaps even more complex are the societal and political ramifications of geologic repositories, which have been perceived in a negative way by the affected states and most localities since the earliest days of siting. Through the years since the beginnings of the search for a repository DOE continues to examine every reasonable method of achieving that goal.

This report was initiated at the request of the Office of Civilian Radioactive Waste Management (OCRWM) Headquarters in 1986. It was originally intended to be a short report to serve as a primer for a new OCRWM staff and as a reference for others already on staff. The first draft was prepared by Thomas F. Lomenick of the Oak Ridge National Laboratory (ORNL) and Cyrus Klingsberg (under Subcontract to ORNL). In response to numerous reviews and comments by DOE and contractor staff, the report was expanded to include more detail and to cover the chronology of events through December, 1987, when an amendment to the first Nuclear Waste Policy Act was passed. Extensive reviews and revisions made by Robert B. Laughon (Battelle Memorial Institute) and Harry W. Smedes (1983) (CER Corporation) contributed substantially to the final report.

Whereas it is not practicable to provide all details and to include all events and activities, the goals of this report are to provide a general review that emphasizes technical aspects, and to serve as a "map" that leads the reader to the sources of detail. In general, this account provides emphasis and detail on the earlier programs that are out of proportion to their importance relative to later years. This was purposely done in an effort to capture and preserve important aspects of the history that heretofore have existed largely in the "gray" literature of obscure office memos, teleconference notes, and letters; or as oral records. Inasmuch as the authors and principal contributors were involved in much of that early history (as well as the more-recent programs), it was considered appropriate and important to record that early record in the light of their conscious knowledge. The later programs are amply documented in detail in numerous readily accessible and available formal reports.

In its present form, the report meets the original objectives and also serves a much broader potential audience that includes DOE/HQ staff, DOE Field Office staff, support contractors, the Nuclear Waste Technical Review Board, congressional staff, states, communities, the public, and governments of other countries. Without a record such as this, some of the events and reasons for some of the actions very likely would soon become lost and untraceable because few individual memories are long enough, or accurate enough, to remember all of the events recorded here.

The author expresses his deep appreciation to Nancy K. Smith and Mary Jo Kreger for typing and preparing the report manuscript, Ralph W. Sharpe for technical editing, and Suman P. N. Singh for shepherding the preparation of this report, following the author's retirement from ORNL.

# EXECUTIVE SUMMARY

This record of siting a geologic repository for high-level radioactive wastes (HLW) and spent fuel describes the many investigations that culminated on December 22, 1987 in the designation of Yucca Mountain (YM), as the site to undergo detailed geologic characterization. It recounts the important issues and events that have been instrumental in shaping the course of siting over the last three and one half decades. In this long task, which was initiated in 1954, more than 60 regions, areas, or sites involving nine different rock types have been investigated. This effort became sharply focused in 1983 with the identification of nine potentially suitable sites for the first repository. From these nine sites, five were subsequently nominated by the U.S. Department of Energy (DOE) as suitable for characterization and then, in 1986, as required by the Nuclear Waste Policy Act of 1982 (NWPA), three of these five were recommended to the President as candidates for site characterization. President Reagan approved the recommendation on May 28, 1986. DOE was preparing site characterization plans for the three candidate sites, namely Deaf Smith County, Texas; Hanford Site, Washington; and YM. As a consequence of the 1987 Amendment to the NWPA, only the latter was authorized to undergo detailed characterization. A final Site Characterization Plan for Yucca Mountain was published in 1988.

Prior to 1954, there was no program for the siting of disposal facilities for high-level waste (HLW). In the 1940s and 1950s, the volume of waste, which was small and which resulted entirely from military weapons and research programs, was stored as a liquid in large steel tanks buried at geographically remote government installations principally in Washington and Tennessee. However, as time passed, the need to permanently dispose of the present and projected commercially-generated radioactive waste became evident. The Atomic Energy Act of 1954 (AEA) not only permitted private industry to construct and operate nuclear reactors for generating electricity, but it also assigned to the Atomic Energy Commission (AEC) the responsibility for managing the expected large quantities of HLW. Almost immediately, the AEC, with advice from the National Academy of Sciences (NAS) and U.S. Nuclear Regulatory Commission (NRC) initiated studies to determine the most promising means for the permanent disposal of these wastes. Although many types of rocks were judged to be potentially suitable for containing these wastes, committees of the NAS and NRC recommended in 1955 that rock salt be considered as the host rock for providing long-term isolation of the wastes. Because of this recommendation, salt was the only rock type considered during the late 1950s and 1960s. In addition, because the commercial reactors were, at that time, being constructed primarily in the northeast quadrant of the country only salt-bearing areas in that region, together with deposits in Kansas, were considered for a repository. Furthermore, because the AEC required a separate facility for the disposal of long-lived alpha-contaminated wastes in contrast to commercial reactor waste, an abandoned underground mine was considered as potentially useful for the first site.

National, regional and site-specific studies of salt deposits led to field tests which shed important new light on technical issues. These early studies and tests provided the focus for further tests at Lyons, Kansas which the AEC and Kansas Governor Docking tentatively selected as a "demonstration repository". Field tests (referred to as Project Salt Vault) at this site resulted in important new data on rock stability and behavior at elevated temperatures, radiolytic processes, and the major discovery of brine migrating toward a heat source.

In spite of the success of these important tests, the AEC abandoned the Lyons site because of growing concerns about nearby unplugged oil and gas boreholes, nearby solution mining, and increasingly negative attitudes toward the facility by state and local officials. This led to the search for alternative sites in Kansas and to sites on federally owned land in New Mexico and elsewhere.

Along with the shift of the siting effort to the Carlsbad area of southeast New Mexico in 1971-1972, the AEC also began to consider alternatives to geologic disposal of HLW. A major initiative in this regard is the proposed Retrievable Surface Storage Facility (RSSF), major reorganization of the AEC's waste management group to accommodate the expanded siting studies in salt and other rocks. At the same time, the U.S. Geological Survey (USGS) became a major contributor to the siting work. Although the greatest effort in the early 1970s to locate a repository was focused on government owned land in southeastern New Mexico, regional investigations were also begun in the salt deposits of the Paradox, Appalachian, and Michigan basins, and on the Gulf Coast salt domes. Investigations of several rock types (argillite, granite, and volcanic tuff) at the Nevada Test Site and of basalt at the Hanford Site were under way as were preliminary siting studies of bedded salt in the Palo Duro Basin of west Texas. Thus, by the mid-1970s, regions were under study that contained all of the sites that later became nominated as candidates for the first repository. This increased effort was consistent with the projected needs of the nuclear power industry at that time.

In 1976, an even more ambitious siting effort was initiated by the Energy Research and Development Agency (ERDA) with the formation of the National Waste Terminal Storage (NWTS) program. This program envisioned several repository sites in different rock types in different sections of the country. Although it was felt at the beginning of this program that geologic repositories must be available to accommodate wastes from fuel-reprocessing facilities in the early 1980s, it soon became apparent that delays in reprocessing spent fuel would occur due to concerns about the proliferation of nuclear materials for non-peaceful applications, and to the public's perception of nuclear safety. Thus, by the end of the 1970s it was decided that the siting period could be extended because a repository would not be needed until the 1990s.

The approach of the NWTS program was to select multiple sites in several different rock types. This philosophy was supported by recommendations of President Carter's Interagency Review Group (IRG) on Nuclear Waste Management. In addition, the participation by the ERDA, successor to the AEC, in the Stripa Project in Sweden was a reflection that several foreign nations were investigating rock types and deposits other than salt for possible repositories. In some of these countries, no salt was present; in others, clays or rocks such as granite were vastly more abundant or viewed as preferable for other reasons.

# 1. INTRODUCTION

This report provides a comprehensive account of the process for siting a geologic radioactive-waste repository from the inception of that process in 1954. Some aspects of siting have been discussed in reports related to the broader subject of waste management (Baillieul, 1987; Brown, 1976; Hewlett, 1979; McIntosh, 1984).

Julius Rubin (1972) presented a brief summary of the evolution of the AEC policies in radioactive waste management and presented the status of thinking as of 1972. The keystone of that thinking was for engineered storage in a group of modular concrete structures while the solution to the problem of permanent disposal was being methodically pursued. It was expected that the ultimate solution would be some form of geologic disposal. As a consequence, a Pilot Plant Repository was conceived as a means to confirm analytical predictions of overall repository safety and to demonstrate that handling, emplacement, and retrieval of waste canisters from a geologic repository can be routinely performed.

In a chronology of selected aspects of the Atomic Energy Commission's (AEC's) management of radioactive waste, Daniel Metlay (1978) provided insights (his "interpretations") of significant trends of policy, organizational behavior, perceptions, and lessons learned. His report includes information on disposal concepts and on the Lyons, Kansas, site that supplements the current report. It also contains interesting observations on the controversy of whether the technological solution to waste disposed is easy or difficult.

An informal chronology of developments was prepared by John Mullaney (1980) and distributed to staff at DOE. This brief account highlighted selected key statements that influenced or announced the direction of waste programs—principally reports, press releases, Presidential statements, and congressional regulations.

Alice Buck (1983) provided a history of the AEC (1946–1974). Although this brief report makes no mention of waste disposal, it nevertheless constitutes a useful reference that traces the organizational antecedents of the major programs and offices of DOE.

A comprehensive analysis of the policies and approaches to waste management in the United States and other countries is provided in a well-researched book by Luther Carter (1987), who discussed the lack of planning for waste disposal that marked the optimistic early years of nuclear power; chronicled and analyzed the controversies and technological investigations that have arisen as scientists, environmentalists, members of Congress, and federal agencies have tried to keep pace with the problems of disposal; and described how most efforts in the United States, Europe, and Japan to establish permanent repositories have been beset by public opposition, questions of fairness, and technological uncertainty. The recommendations made by Carter probably were instrumental in influencing the Congress, for the principal tenets of the subsequent amendment to the Nuclear Waste Policy Act (NWPA) were closely similar to Carter's recommendations.

In reviewing the record of siting, a large volume of pertinent material was assembled. All of this could not be managed in the principal part of the text; however, through the use of appendixes, a more detailed account of selected aspects of the siting process has been preserved.

The AEC was established by the Atomic Energy Act of 1946 and officially began on January 1, 1947, when it took over from the Manhattan Engineer District the massive research and production facilities built during World War II to develop the atomic bomb. The AEC existed until January 19, 1975, when its functions were incorporated into a broader federal agency, which was created by the Energy Reorganization Act of 1974.

By that Act, the research and development (R&D) activities were taken over by Energy Research and Development Administration (ERDA), and the regulatory and licensing activities were taken over by the U.S. Nuclear Regulatory Commission (NRC). ERDA was abolished in late 1977 by the DOE Reorganization Act, wherein Congress created a cabinet-level department which had even broader federal responsibilities than did its predecessor agencies.

This report traces the major siting events in chronological order from 1954 through 1987. In most cases, several consecutive years are grouped and discussed as a single period, which commonly begins with a major siting event. For the early years, the report covers the principal site investigations that were undertaken; the siting criteria and disposal concepts that were used at the time; the nature and extent of cooperation and coordination of activities with the affected states, Indian Tribes, and local governments; and the technical issues that had a bearing on siting. In the middle years, after most site investigations had been initiated, this report pays more attention to the organizational efforts and the institutional structures that were developed to carry out the more formalized siting policies. The last years are devoted to an examination of the siting aspects of the NWPA, the Nuclear Waste Policy Amendments Act of 1987 (NWPAA), and to the siting reports and documents that resulted from the passage of those Acts (NWPA, 1982; NWPAA, 1987). The siting actions that have been initiated since the NWPA was enacted provide the final chapters of this report.

During the 34-year period, 1954 through 1987, siting studies were undertaken in more than 60 regions, areas, and sites throughout the country. In many cases, the decisions to pursue investigations at these sites were made because of specific siting criteria, while in others the decision to initiate work was made in conjunction with a general policy of expanded siting activities; a policy that resulted in the study of many rock types at multiple locations throughout the country. In general, the activities are discussed in chronological order; however, for some studies where the work has continued over many years, separate discussions are found in several different time periods. A tabulation of these regions, areas, sites, and test facilities, as linked to the rock types under investigation, is given in Table 1.1. A general summary of the field tests through 1982 is given by Stein and Collyer (1983); specific tests are described in appropriate sections of this report.

Prior to 1954, the nation's inventory of HLW was small and entirely the result of military weapons and research programs (Culler and McClain, 1957). These wastes were stored principally in steel and concrete tanks at two federally owned reservations in Tennessee and Washington (Hedman, 1956). During the decade after World War II, the AEC called on the USGS, the Weather Bureau, other government agencies, and various universities, for assistance in addressing the general problems of waste containment at the federal reservations (Culler and McClain, 1957) and did not pursue alternative methods (such as geologic disposal) for disposition of those wastes.

The AEA of 1954 was a major revision of the 1946 Act. It made possible greater participation by private industry and more cooperation with other countries in developing the peaceful uses of atomic energy and provided the direction and organizational structure for the siting of facilities for the disposal of HLW. This important inclusion of siting provisions is the basis for considering 1954 as the real starting point of this chronology of siting activities for a HLW repository. Since 1954, the AEC, ERDA, and DOE have increasingly sought to provide safe and environmentally acceptable repository sites.

Until 1978, the waste to be disposed of was considered to be liquid—the product of chemical reprocessing of the spent fuel during which process plutonium and unfissioned uranium would be reclaimed. However, after President Carter indefinitely banned the reprocessing of spent fuel, the waste form to be disposed of was solid-spent-fuel assemblies and cladding hulls.

**Table 1.1 Rock types, regions[a], areas[b], sites[c] and test sites considered in the siting programs of the AEC, ERDA, and DOE**

| Rock Type | Regions | Areas | Sites | Test sites |
|---|---|---|---|---|
| Bedded Salt | | | | |
| (Permian Basin) | Central Kansas | | Hutchinson N.A.S. | Carey Mine |
| | | | Lyons Mine | Lyons Mine |
| | | | Suppl. Site 1 | |
| | | | Suppl. Site 2 | |
| | | | Suppl. Site 3 | |
| | | | Suppl. Site 4 | |
| | | | Suppl. Site 5 | |
| | | | Suppl. Site 6 | |
| | | | Suppl. Site 7 | |
| | | | Suppl. Site 8 | |
| | SE New Mexico | Los Medaños | Waste Isolation Pilot | |
| | | | Plant | |
| | | Carlsbad Potash Mines | | |
| | | Clovis-Portales | Bedded Salt Pilot | |
| | | Mescalero Plains | Plant | |
| | West Texas/Oklahoma | Dalhart Basin | | |
| | | Palo Duro Basin | Deaf Smith Co. Site | |
| | | | Swisher Co. Site | |
| (Paradox Basin) | Paradox Basin | Salt Valley | | |
| | | Shafer Dome | | |
| | | Davis Canyon | | |
| | | Elk Ridge | David Canyon | |
| | | Lavender Canyon | | |
| | | Lisbon Valley | Lavender Canyon | |
| (Arizona Deposits) | | Luke Salt Body | | |
| (Salina Group) | | Supai Salt Basin | | |
| | Appalachian and Michigan | Alpena Co., MI | | |
| | Basins in | NE Ohio | | |
| | MI/NY/OH | SW New York | | |
| (Other) | | | | |
| | Williston Basin | | | |
| | Virginia River Valley | | | |
| Interior Salt Domes | | | | |
| | LA Salt Dome Basin | Rayburn's Dome | | |
| | | Vacherie Dome | | |
| | | | Vacherie Dome | Avery Island Dome |
| | MS Salt Dome Basin | Cypress Creek Dome | | |
| | | Lampton Dome | Cypress Creek | |
| | | Richton Dome | Dome | |
| | TX Salt Dome Basin | Keechi Dome | | |
| | | Oakwood Dome | Richton Dome | |
| | | Palestine Dome | | |
| Argillaceous Rocks | | | | |
| and Deposits | | | | |
| | Pierre Shale | | | |
| | Triassic Basins | | | |
| | Green River Formation | | | |
| | Gulf Coast Clays | | | |
| | Indiana Shales | | | |
| | | | | Syncline Ridge, NTS |
| | | Eleana Formation NTS | | Unnamed site, ORNL |
| | | Conasauga Formation | | |

**Table 1.1 (continued)**

| Rock Type | Regions[a] | Areas[b] | Sites[c] | Test sites |
|---|---|---|---|---|
| Limestone | | Baberton, OH<br>Kansas City, MO | | |
| Chalk | Western Alabama<br>Eastern Texas<br>Mid-Continent/Great Plains | | | |
| Talc | Appalachian Region | | | |
| Tuff | Basin and Range | Nevada Test Site | Yucca Mountain | |
| | | | | G-tunnel (Ranier Mesa) |
| Basalt | Pasco Basin | Hanford Site | Reference Repository Location | Near-Surface Test Facility |
| Crystalline Rocks | | Nevada Test Site | Wahmonie Stock<br>Calico Hills<br>Timber Mountain | |
| | | | | Climax Stock |
| | | | | CSM Experimental Mine,<br>Stripa Mine, Sweden<br>URL, Manitoba, Canada |
| | Northeastern (CN,ME,MA,NH,NJ, NY,PA,RI,VT) | Bottle Lake Complex (NE-2)<br>Sebago Lake Batholith (NE-4)<br>Cardigan Pluton (NE-5) | | |
| | North Central (MI,MN,WI) | Wolf River Batholith (NC-3)<br>Undifferentiated Granites (NC-6)<br>Undifferentiated Granites (NC-7)<br>Archaen Gneisses and Central MN Granites (NC-10) | | |
| | Southeastern (GA,MD,NC,SC,VA) | Lovingston Massif (SE-2)<br>Virgilina Gneiss (SE-3)<br>Rolesville Pluton (SE-4)<br>Elk River Complex (SE-5)<br>Woodland Gneiss Complex (SE-7) | | |

Explanations of acronyms:
CSM: Colorado School of Mines.
NTS: Nevada Test Site.
ORNL: Oak Ridge National Laboratory.
URL: Underground Research Laboratory.

[a]Region: Tens of thousands to hundreds of thousands of square miles, determined by occurrence of geologic properties of the formation or system that are thought to be favorable.

[b]Area: Approximately 1000 square miles; identified as the result of a reconnaissance of a region.

[c]Site: A few square miles; an area slightly larger than a repository.

# 2. PERIOD: 1954–1961

## 2.1 PRINCIPAL EVENTS AND STUDIES

Although the enactment of the Atomic Energy Act of 1954 (AEA) provided the legal framework for the generation of electricity by nuclear reactors and thus the impetus for locating waste disposal facilities, the earliest noteworthy siting event occurred in 1955 when the first conference on waste disposal was held at Princeton University under the auspices of the AEC and National Academy of Sciences (NAS) and NRC. The principal conclusion drawn from this conference was that salt deposits were the most promising host rocks for waste disposal (NAS and NRC, 1957). This finding led to literature-review studies by the U.S. Geological Survey (USGS) of the characteristics of rock salt deposits in the United States (Pierce and Rich, 1958). Shortly after that study the Geotechnical Corporation, as consultant to the Oak Ridge National Laboratory (ORNL) published a report on the location, extent, and wastes; and arranged a conference with oceanographers to explore possible waste disposal in the oceans.

### 2.1.2 The NAS and NRC Committee On Waste Disposal.

To generate programs that would lead to the safe and permanent disposal of HLW, the AEC requested in 1954 that the NAS and NRC assemble a committee of earth scientists to examine the potential for disposing of these wastes in rock formations within the subsurface. Specifically, the committee was charged with (1) assembling the available and pertinent data for geologic disposal (2) identifying specific information needs for potential disposal schemes and (3) defining research and development activities for the HLW program (NAS and NRC, 1957). It is noteworthy that this committee was also designated to serve as a continuing advisor to the AEC on matters related to the earth-science aspects of high-level radioactive-waste disposal.

The NAS–NRC Committee Meeting on Waste Disposal was held at Princeton University in Princeton, New Jersey, September 10–12, 1955. This conference was attended by 65 scientists and engineers representing many disciplines from government, universities, and private industry (NAS, 1957). The findings and recommendations from this and related meetings by committee members during the ensuing 2 years were of paramount importance in forming the basis for the AEC's repository siting work and in exerting influences on all subsequent investigations. Key findings of the committee were:

- Waste may be disposed of safely in a variety of ways and at a large number of sites in the United States; but, conversely, there are many large areas in which it is unlikely that disposal sites can be found.
- The research to determine feasibility of disposal has for the most part not yet been done.
- It may require several years of research and pilot testing before the first such disposal system can be put into operation. Until such time, storage in tanks will be required for the wastes.
- Disposal could be greatly simplified if the waste could be solidified into a relatively insoluble form.
- In the future, the injection of large volumes of dilute liquid waste into porous rock strata at depths greater than 5,000 ft may become feasible, but means of rendering the waste solutions compatible with the mineral and fluid components of the rock must first be developed.

Specific recommendations made by this committee were:

- Storage in tanks is at present the safest and possibly the most economical method of containing waste.

- Disposal in salt is the most promising method for the near future. Research should be pushed immediately on the structural problem of stability vs size of cavities at a given depth on the thermal problem (i.e., getting rid of the heat to keep it down to acceptable levels), and on the economics of such disposal.
- Next most promising method seems to be stabilization of the waste in a slag or ceramic material, thus forming a relatively insoluble product. This could be placed in dry mines, surface sheds or large cavities in salt.
- Disposal of waste in porous beds interstratified with impermeable beds in a synclinal structure is a possibility for the more distant future. This is of particular interest for disposal of the large volumes of waste to be expected in the future. Very difficult and complex problems have to be solved before it will become feasible. The reaction of the waste with connate waters or constituents of the rocks soluble in the waste solution will have to be studied. The composition of the rocks and the connate waters are both variable as will be the composition of the waste solutions so that an almost infinite variety of circumstances result. In general, acid aluminuous waste would almost certainly tend to form precipitates which would clog pore spaces. The problem would have to be solved first for a given bed at a given site for a given waste solution at a given dilution.
- The removal of $^{137}Cs$ and $^{90}Sr$ from the waste would make disposal somewhat easier for the waste free of these isotopes, but their removal does not change qualitatively the recommendations made in the report.
- In the complex relationships among (a) storage time of waste for cooling, (b) transportation cost in shielded carriers, and (c) distance to disposal site. The last of these aspects must be considered before location of any plant producing large quantities of waste. We must remember that there are large sectors of the country where disposal is not possible.
- Continuing disposal of certain (large volume) low-level waste (LLW) in the vadose water zone (above the water table), is of limited application and probably involves unacceptable long-term risks.
- The movement of gross quantities of fluids through porous media is reasonably well understood by hydrologists and geologists, but whether this is accomplished by forward movement of the whole fluid mass at low velocity or whether the transfer is accomplished by rapid flow in "ribbons" is not known. In deep disposal of waste in porous media, it will, in many cases, be essential to know which of these conditions exists. This will be a difficult problem to solve.
- The education of a considerable number of geologists and hydrologists in the characteristics of radioactive wastes and its disposal problems is going to be necessary.

The committee's finding that salt deposits were the most promising host rocks for waste was based on several favorable properties of rock salt—namely, its high thermal conductivity, high plasticity that enables it to seal fractures, its long-term stability, its good compressive strength, the low cost of cavern excavation, and abundant and widespread distribution of salt deposits throughout the county.

The recommendation by the NAS and NRC that salt deposits were the most promising host rocks was affirmed in subsequent reports (such as NAS and NRC, 1970; American Physical Society, 1978). The concept of pumping these wastes into deep and porous sandstone beds or other permeable and porous rocks that are interstratified with impermeable beds in deep sedimentary basins was seriously considered (see Sect. 2.2.2.); however, this method of disposal commands little or no support today.

The recommendation of the Committee on Waste Disposal to investigate salt deposits for the permanent containment of HLW was so strong that a special report on the characteristics and distribution of salt deposits in the United States was included as an appendix in its September 1957 report (NAS and NRC, 1957). That report identified large deposits of bedded salt in the Paradox Basin in southeast Utah and southwest Colorado, in the Delaware Basin of southeast New Mexico and west Texas, in central Kansas, in the Michigan Basin, and in the Northern Appalachian Basin of northeast Ohio and western New York and Pennsylvania. Salt domes in the Gulf Coast region were listed. Data on the depths and extent of mechanical workings in these salt deposits were also included (NAS and NRC, 1957). This work, which may be considered as the first step in the siting process for repositories in rock salt, showed that potential disposal sites in salt would be limited to a few geographic regions of the country.

### 2.1.3 Studies Of Deep-Well Injection

Significant experience with injecting fluids into porous formations had been accumulated within the petroleum industry by the 1950s, and it is logical that this technology be examined for its potential application to waste disposal. As a follow-up of the NAS and NRC report (see Sect. 2.1.2), in 1957, the AEC requested the American Association of Petroleum Geologists (AAPG) to evaluate the feasibility of this concept. After a year's study, a committee of the institute submitted a report concluding that the injection of radioactive wastes into clearly defined, porous reservoirs where the waste solution would be contained for a lengthy period was a reasonable possibility (AAPG, 1968). The major problems cited by this subcommittee were those of ensuring waste confinement, providing for adequate heat dissipation, and protecting the system from corrosion and radiation damage. The subcommittee suggested, moreover, that if the development of this approach were pursued, a suitable site should be selected through geological and geophysical exploration that was independent of any oil- or mineral- producing operations.

The USGS had been studying the possibility of injecting liquid waste into strata that lie at great depths in sedimentary basins. These studies were summarized in 1961 (Love and Hoover, 1961). In 1958, the AEC requested the American Petroleum Institute (API)) to identify potentially suitable sites for deep-well injection. A committee, formed by the AAPG compiled and interpreted available data on subsurface geologic and hydrologic systems within six geologic basins (Appalachian, Michigan, Salina, Denver, San Juan, and a small synclinal basin within the Valley and Ridge subprovince of the Appalachian Mountains) of the United States for use in the selection of potential sites for waste disposal by deep-well injection (API, 1959). Later, the AAPG supplied additional valuable geological information, and engineering data applicable to the disposal of radioactive wastes into subsurface basins (AAPG, 1964).

### 2.1.4 Study Of Salt Deposits by the USGS

Aided by the conclusion of the NAS and NRC Committee on Waste Disposal that rock salt would provide the most promising host for the disposal of HLW, the AEC commissioned the USGS to prepare a detailed report on the rock salt deposits of the United States (see Fig. 2.1). This report was published in a preliminary form in 1958 and in final form in 1962 (Pierce and Rich, 1958, 1962) and included the geographic distribution of salt deposits throughout the country. The USGS included readily available data on factors such as structure, stratigraphy, and the thickness and depth of the salt formations. This detailed and comprehensive report provided a good basis on which to build further consideration of repositories in rock salt.

### 2.1.5 Survey by the Geotechnical Corporation

In February 1958, the Geotechnical Corporation published a report on possible storage of waste in salt cavities in the northeastern United States (Geotechnical Corp., 1958*a*). This report was the result of studies made under a contract with ORNL to provide data for the consideration of a disposal site in the region.

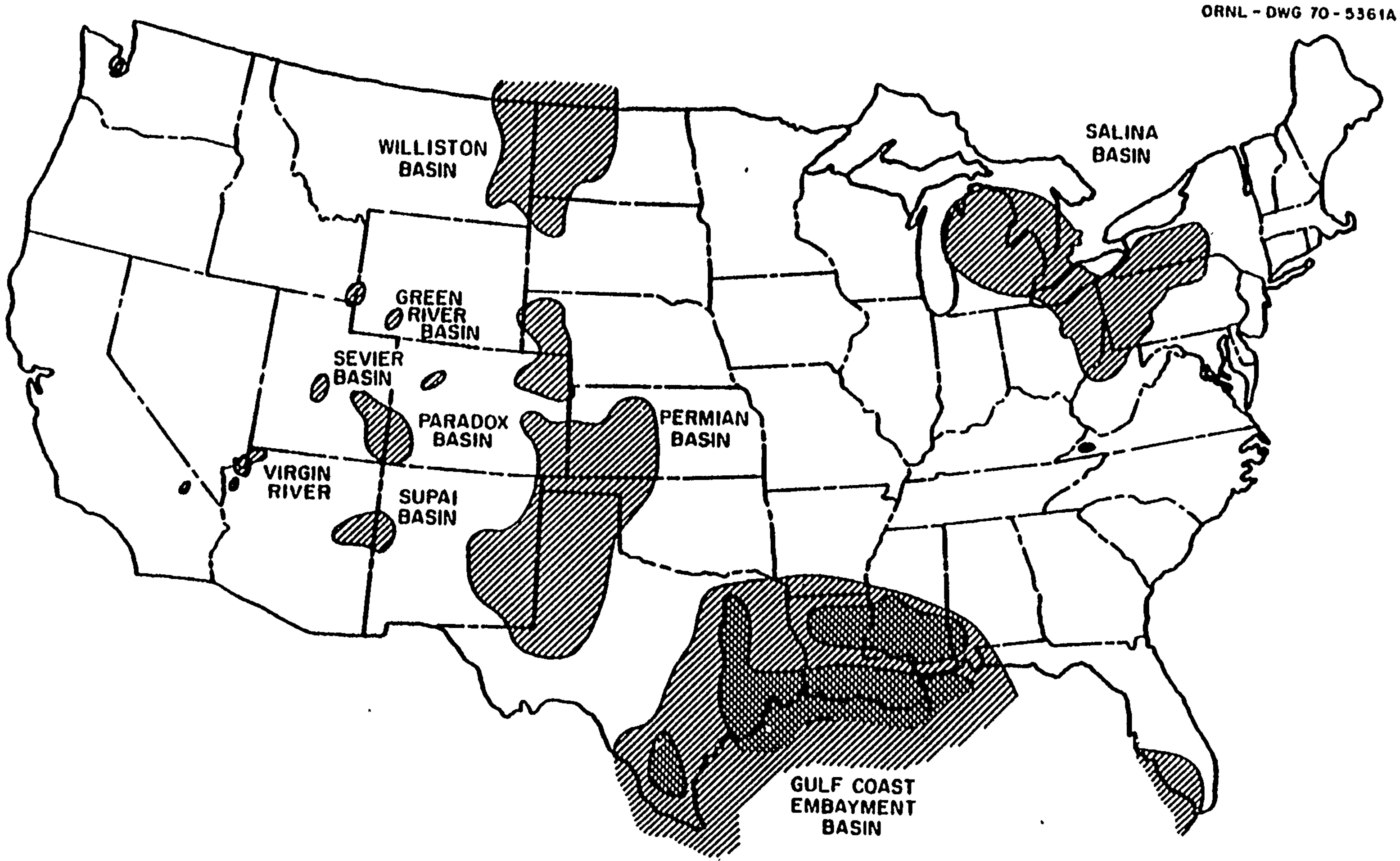


Fig. 2.1 Map of rock-salt deposits in the United States.

Findings of this study concluded that: (1) mined-out space in salt, as created by operating mines, was only available at that time in New York, Michigan, and Kansas; (2) depths to suitable salt deposits were less in Kansas than in the other two states; (3) demographic and waste-transportation factors appeared to favor Kansas; (4) two military installations, one each in Kansas and New York, were underlain by potentially suitable salt beds; and (5) Kansas, given all the factors, appeared to be the most promising state in which to continue further studies on bedded salt.

### 2.1.6 Study Of The Hutchinson, Kansas, Naval Air Station

The first site-specific study for an HLW repository was undertaken in 1957 and 1958 by the Geotechnical Corporation (1958*b*). Stimuli for this effort were an announcement by the U.S. Navy that it would close the Naval Air Station at Hutchinson, Kansas, and the conclusions from the previous studies this central Kansas represented a favored locality for a potential disposal site in salt (Geotechnical Corp., 1958*a*, 1958*b*).

The report on the Geotechnical Corporation study (1958*b*) was released in January 1958 and included data on geographic factors, general geology, surface geology and groundwater geology of the rocks above and below the salt formation, control of lands, and development of storage space at the 1056-ha (2640-acre) Naval Air Station. Most of the data for this study were obtained from available literature sources; however, two core holes were drilled on the site to confirm the presence of the salt deposits and to select potential disposal horizons (Geotechnical Corp., 1958*c*). Largely because of the need to construct shafts and underground excavations at the site, it was not considered further as a test facility or a waste repository.

### 2.1.7 Study Of The Carey Salt Mine, Hutchinson, Kansas

In 1958, a siting study was initiated to select a salt mine for testing the behavior of synthetic liquid waste within an underground space in a bed of rock salt (Geotechnical Corp., 1958*c*). The selected mine was to be used by ORNL for carrying out a series of tests in a specially excavated cavity this would be heated by electrical heaters to simulate radioactive-decay heat. Likewise, specially formulated chemical fluids would simulate the waste solutions. At this time, liquid wastes were considered to be the only waste form for disposal because a solidification process had not been perfected.

The Geotechnical Corporation siting study consisted of comparing the lithologic characteristics of the salt section at Hutchinson, Kansas, with those in mines located at Retsof, New York, and Detroit, Michigan. Existing geologic data were used for developing the stratigraphic columns at the New York and Michigan mines. Several core holes were drilled into the ceiling and floor of the Kansas (Carey) mine in order to provide the needed detailed information at the site (Geotechnical Corp., 1959). Solely on the geologic characteristics of the salt beds being worked at these mines, the investigators concluded that any of the three mines would be suitable for hosting the experiments. Because only the Carey mine at Hutchinson, Kansas, had a suitable thickness of salt below the mine floor in which to contain the experimental cavity, it was subsequently selected for the tests (Geotechnical Corp., 1959).

## 2.2 PRINCIPAL ELEMENTS OF THE SITING PROCESS

### 2.2.1 Criteria

In 1955–1957, during the early studies by the NAS and NRC, the main and perhaps only criterion for siting geologic repositories was the presence of rock salt within the subsurface. However, the availability of water transportation was cited as a secondary factor for siting within the Great Lakes and the Gulf Coast regions (NAS, 1957). Although they were referred to in early studies as siting requirements rather than as criteria, they are criteria nonetheless. Those mentioned in the early reports by the USGS (Pierce and Rich, 1958; 1962) are (1) presence of impermeable enclosing beds, (2) suitable thickness, and (3) suitable purity. Those established by Geotechnical Corporation (1958*a*) are (1) adequate volume of dry storage space, (2) impermeable conditions, (3) host rocks with sufficient thermal conductivity to dissipate heat; (4) sufficient structural strength of the excavated rock to prevent collapse, (5) no production of noxious gases, (6) rock that will not react chemically with the waste, (7) population density, and (8) transportation costs,

In general, the siting criteria used for study of the Hutchinson Naval Air Station site were similar to those for the broader study of the northeastern states conducted earlier by the same firm (see Sect. 2.1.4) (Geotechnical Corp., 1958*b*). The northeastern quarter of the United States was expected to develop a power reactor industry more rapidly than other regions of the country. Therefore, a need for a spent-fuel reprocessing plant and approved geologic repository was anticipated to develop there sooner.

From general geologic and engineering data, mined-out cavities in salt deposits were determined by the AEC and ORNL to meet the specifications for the underground disposal of HLW. In addition, for the Carey salt mine siting study, which was carried out in 1961–1962, it was also deemed necessary for the salt section that was to house the experiments to be of high purity or to be free of interbeds such as shale or dolomite (Geotechnical Corp., 1958*c*; Parker et al., 1959) because impurities or interbeds could affect the test data in an unknown manner and multiply any transfer value of results.

In summary, only very generalized siting criteria were developed for the period 1954–1961. The criteria so formulated were largely applicable to bedded salt, the only rock type under serious consideration at the time.

### 2.2.2 Disposal Concepts

Because of the infancy of the power-reactor and waste disposal programs in the country during the first 3 years (1954–1957) of this period, there was no apparent consensus on the preferred repository concept for disposal. Both liquid and solid wastes were considered for disposal in existing abandoned mines, specially excavated underground caverns, and by injection into deep boreholes. However, by the time (1958) the Geotechnical Corporation had studied the salt deposits in the northeastern states, it was felt that abandoned mines probably offered the best means for disposal.

The first nuclear-powered electrical generating plant was commissioned in 1958 at Shippingport, Pennsylvania. Many additional plants were under construction at that time, and the need for processing spent fuel was foreseen. Because the reactors were concentrated in the northeastern quadrant of the country and transportation costs were of concern, it was planned to locate a spent-fuel reprocessing plant in the quadrant (Geotechnical Corp., 1958*a*). The nearby availability of abandoned mines as potentially suitable waste-disposal sites was a major consideration in siting a reprocessing facility.

Because no mined-out space existed under the Hutchinson Naval Air Station, plans had to be made to sink shafts to the desired depth and then to excavate the disposal facility. This facility would initially be experimental, but that it might eventually serve as a permanent combination processing and disposal facility (Geotechnical Corp., 1958*b*).

The experiments conducted during 1961–1962 at the Carey salt mine revealed that it was impractical to dispose of liquid HLW wastes in salt because of questions about vaporization, loss of containment, and interactions with the rock (Bradshaw et al., 1964). Even before these experiments, consideration was given to solidification of reprocessing liquid HLWs by means such as vitrification. These findings at the Carey salt mine, together with other developments, led to the now-accepted premise that liquid wastes derived from reprocessing would first need to be solidified before being emplaced into a geologic repository.

In summary the disposal methodology developed during this early period, therefore, considered both liquid and solid wastes. Abandoned salt mines were considered the most likely disposal sites. The investigations at the Hutchinson Naval Air Station, however, made it necessary to consider sinking shafts and developing new space for disposal. Experiments conducted at the Carey mine provided evidence that stimulated further efforts of waste solidification.

### 2.2.3 Relationships with States, Indian Tribes, and the Public

State consultation was not formalized in these formative years even though the AEC sought to undertake its responsibility of waste disposal on a cooperative basis with established regulatory agencies in the various states. For the studies conducted by the Geotechnical Corporation in 1958, no formal contacts were made through government channels to secure data in the potentially affected states. It must be acknowledged, however, that the state geologists of New York, Michigan, Ohio, and Kansas supplied technical information and permitted the use of illustrations from their reports for these studies (Geotechnical Corp., 1958*a*; 1958*b*; 1958*c*). In addition, several private companies, notably the International Salt Company, Cayuga Salt Mining Company, Carey Salt Company, and the Independent Salt Company willingly permitted inspection of their mines at Detroit, Michigan; Cayuga and Retsof, New York; and Hutchinson, Lyons, and Kanopolis, Kansas, respectively; supplied maps and details of their mine operations; and discussed the deformation of rock salt in the mined-out openings.

The Kansas Geological Survey (KGS) did not participate in the study of the Hutchinson Naval Air Station; however, KGS staff made its files and publications available to the Geotechnical Corporation (Geotechnical Corp., 1958*b*). For the studies to select a mine for the waste-simulation experiments, the investigators at the Geotechnical Corporation worked closely with the management of the several salt companies. There were apparently no contacts made with state authorities in either Michigan or New York. After the Carey salt mine was chosen, Kansas officials were briefed on the purpose, scope, and extent of the planned experimental project (Empson, 1961).

Although there were no formal arrangements to govern discussions about siting issues and events, professional courtesies were extended to the affected state geologic organizations and other agencies by the investigators through informal briefings and other communications even in the early years. There did not emerge during this period any overt opposition to the efforts being undertaken by the AEC.

### 2.2.4 Technical Issues

Specific technical issues (other than siting requirements) were not addressed in either the USGS reports (Pierce and Rich, 1958, 1962) on U.S. salt deposits or in the Geotechnical Corporation report (Geotechnical Corp., 1958*a*) on the salt deposits in the northeastern states. Because of the regional coverage of both studies and the scoping nature of the latter work, technical issues had not yet been raised.

No new technical issues were raised in the abbreviated study by the Geotechnical Corporation of the Hutchinson Naval Air Station. Although the assumed low cost for developing disposal space and the availability of government-owned land were cited as reasons for possibly using this site (Geotechnical Corp., 1958*b*), the factors related more to siting criteria than to technical issues such as waste form, waste package, solubility, and rock mechanics.

The principal technical issues in the tests at the Carey Salt Company mine at Hutchinson were related to the interactions of the heated, simulated liquid waste and the host rock salt. Of secondary importance was the potential for migration of the wastes through the salt bed. As noted in Sect. 2.2.2, the experiments at this salt mine did much to convince the AEC that liquid reprocessing wastes would need to be solidified before they could be disposed of within a subsurface facility and provided stimulus for further research on the use of borosilicate glass to contain the waste.

As the principal technical issues developed during the period 1954–1961, the structural stability of the host rock salt and the chemical interaction of simulated liquid wastes and salt were rather narrowly defined in that only one rock type was involved. However, these early deliberations had considerable future impact. In the first case, structural (rock mechanics) stability into the decades ahead remained an important issue for salt, as well as other rock types, In the second, a host of subissues related to waste solidification emerged and required appreciable investigative attention (see Sect. 2.1.6).

### 2.2.5 Participating Organizations

The earliest NAS and NRC and USGS work during 1954–1957 was contracted directly with the AEC. Studies undertaken in the latter part of the period, that is, 1957–1962, were conducted largely by the Geotechnical Corporation under subcontract to ORNL which was a prime contractor to the AEC.

The study of salt deposits in the northeastern states as well as the siting investigation at the Hutchinson Naval Air Station were conducted by the Geotechnical Corporation of Dallas, Texas, for ORNL. For the project at the Carey salt mine, the AEC, its subcontractors, and the Carey Salt Company all played important roles in the siting investigations. The actual experiments within the mine were largely the responsibility of the AEC and ORNL.

# 3. PERIOD: 1962–1972

## 3.1 PRINCIPAL EVENTS AND STUDIES

This period, like the 8 years preceding it, centered on investigations of the waste-disposal potential of rock salt and, in particular, bedded salt. This period was further characterized initially by high expectations of further advances built upon the earlier salt-related investigations. However, developments in siting during this decade transformed some of these expectations into disappointing setbacks for the overall repository program.

The State of Kansas was clearly the focus of this investigative period, which started with the highly successful experimental testing during Project Salt Vault, conducted at Lyons, Kansas; was followed by eventually unsuccessful efforts to site a "demonstration repository" at the same mine used in that project; and concluded by unsuccessful additional studies to locate and evaluate other sites in Kansas for a similar demonstration facility. Possibly the most noteworthy realizations made during this period concerned (1) certain technical issues regarding rock salt and its dissolution by groundwater and (2) increasing disagreements between the U.S. and state governments.

### 3.1.1 Project Salt Vault

With successful efforts at ORNL and Hanford to convert liquid HLW into solids for geologic disposal (see Appendix A), in 1962 the AEC requested ORNL to conduct a demonstration test in a suitable salt formation in an effort to establish the practicality of using salt deposits for the disposal of solidified wastes. The engineering and scientific objectives of this test included (1) the demonstration of waste-handling equipment and techniques; (2) the determination of gross effects of radiation (up to $10^7$ gray) on factors such as hole closure, floor uplift, and salt-pillar deformation within a temperature range of 100° to 200° C; (3) the determination of the radiolytic production of chlorine; and (4) the collection of data on the plastic flow of salt at elevated temperatures (Bradshaw et al., 1964). The latter information was to be used in the design of an actual disposal facility.

The Project Salt Vault demonstration was carried out in the Carey Salt Company mine located at Lyons, Kansas. Fourteen irradiated Engineering Test Reactor fuel assemblies contained in seven canisters served as the radiation sources. Individual experiments commenced in mid-1964, and testing extended until late 1967.

Although no formal site-selection studies were conducted by ORNL to identify a mine for this demonstration test, three additional sites were also considered: (1) the Carey Salt Mine at Hutchinson, Kansas; (2) the Naval Air Station at Hutchinson, Kansas; and (3) the Project Gnome site in New Mexico (Bradshaw et al., 1964).

The Carey Salt Company ruled out the use of its Hutchinson mine, whereas the Naval Air Station was rejected by ORNL because of the need to develop a complete mine installation there, including shafts and hoisting equipment. Even though the Gnome site was on government-owned land, it was rejected because of the poor quality and nonrepresentative nature of the salt at that location and the potential for conflicts with other government agencies in using the site (Bradshaw et al., 1964).

### 3.1.2 The Demonstration Repository—Lyons, Kansas

Recognizing that a permanent solution for the HLW problem was required, the AEC with the support of NAS and NRC and members of the geological community, sponsored further studies, principally through ORNL, to examine the suitability of bedded-salt formations as a final repository for solidified wastes. As a first step in implementing an overall waste management policy, the AEC published in the *Federal Register* an appendix to 10 CFR Part 50 which required industry to solidify its HLWs and ship them to a federal repository (*Federal Register*, 1969). In June 1970, the AEC, along with Governor Docking of Kansas, announced the tentative selection of a site near Lyons, Kansas, for a demonstration salt-mine repository (AEC, 1970).

The facility was to be located in an area that was tectonically stable and contained geographically extensive, thick, and relatively flat-lying beds of rock salt. Central Kansas, lying within the stable interior of the United States, was believed to be geologically and hydrologically well suited as a site for a demonstration repository (Bradshaw et al., 1964).

An examination of the geological aspects of three rock salt formations (namely those underlying central Kansas, west-central New York, and southeastern Michigan) indicated that all three areas met the minimum requirements for a waste repository. If it were necessary that a brine-injection capability for the disposal of excess excavated salt would be required, the central Kansas area was judged superior to either of the other areas because of the sizeable injection volume of the deeper, saline-water aquifers in the Arbuckle Formation. Other, perhaps more marginal, geological advantages that were attributed to central Kansas were (1) the depth to the disposal horizon was shallower; (2) the thickness and areal extent were greater; (3) the area was in seismic risk zone 1 (i.e., expected minor damage); and (4) because extensive experimental work had already been done there, much more was known about the detailed nature and properties of the Kansas salt (Hutchinson Salt Member of the Wellington Formation). This latter information would be pertinent to the design of a repository (Bradshaw et al., 1964).

From considerations other than geological siting, the Lyons, Kansas, mine of the Carey Salt Company appeared to be uniquely suitable because (1) it was the only available, accessible, nonproducing mine in any of the three geologically acceptable areas; (2) it was served by two major railroads and a U.S. highway; (3) much detailed information on the mine and its setting was already available from the 3-year Project Salt Vault experiment that had been conducted there (Bradshaw et al., 1969; Culler, 1971); and (4) a favorable reception by state politicians, local officials, and private citizens was expected (Bradshaw et al., 1969).

After conducting additional investigations of the area, including drilling and testing three deep core holes, the AEC concluded in the fall of 1971 that, because of concerns (see Sects. 3.1.3 and 3.1.4) about the suitability of the Lyons site, efforts there would be discontinued. However, searches would be made for other sites within central Kansas for a demonstration repository (AEC, 1971).

### 3.1.3 Supplemental Demonstration Repository Sites--Central and Western Kansas

In the autumn of 1971, ORNL contracted with the KGS to study central and western Kansas for the purpose of identifying potential repository sites to take the place of the one at Lyons, Kansas. By using its own generic siting criteria, the KGS selected eight study areas for evaluation (University of Kansas, 1972*a*). Data for these evaluations were derived primarily from the published literature and file sources of state agencies. Included in the siting evaluation was information on areal geology; groundwater hydrology; population; oil and gas fields; pipelines; exploration and development boreholes; and the depth, thickness, and purity of the salt. A subjective ranking of the areas by the KGS identified three areas as having much greater potential than the others for further study. Two were in north-central Kansas, and the third was in west-central Kansas. Subsequent to the selection of these three areas, ORNL contracted with the University of Kansas Center for Research (UKCR) and the KGS to make further, more-detailed studies of them (University of Kansas, 1972*b*).

For each site, a single, deep test hole was drilled to determine the geologic and hydrologic characteristics of the underlying rocks. Cores were obtained for all of the salt sections. Pumping tests were also performed in the holes to measure the hydrologic characteristics of the rocks above, as well as those below, the salt sections. In addition to investigating the hydrologic features at the three sites, the contractors also gathered information on some of the cultural features within the areas. Primarily on the basis of criteria that were developed at ORNL (see Sect. 3.2.1), the Kansas investigators concluded that none of the sites contained salt with the thickness and purity considered necessary for further study. Using the same criteria, the investigators dismissed the Lyons site as having an inadequate buffer zone because of adjacent solution mining and too many nearby unplugged gas-and oil-drill boreholes. Despite their rejection of these several areas as well as the Lyons site, the KGS suggested that two other areas, one in the north-central part of the state and the other in the south-central part, might be considered for future studies, but they were not explored (University of Kansas, 1972*b*).

### 3.1.4 Waste-Management Alternatives

In 1972, as an early part of an expanded waste management program, the AEC instituted a comprehensive assessment of potential alternative methods for long-term management of HLW (Schneider and Platt, 1974; AEC, 1974*a*). The study was prepared by Batelle's Pacific Northwest Laboratory and included information relevant to technical feasibility, safety, cost, environmental considerations, policy conflicts, public response, and R&D needs for (1) disposal in terrestrial locations (land, sea, and polar ice sheets); (2) disposal into space, and (3) elimination by nuclear transmutation. Feasibility was assessed on the basis of currently available, or near-future, technology. The USGS prepared the part that dealt with geologic and hydrologic considerations. That part was published as Vol. 2 and has also been published separately as a USGS report (Ekren et al., 1974).

Five geologic disposal concepts were considered that emphasized different emplacement techniques for liquid or solidified HLW in mined cavities and drilled holes. Several methods for forming the cavities, as well as different waste-handling modes, were also examined.

Potential disposal concepts developed for ice sheets included (1) the emplacement of canisters in shallow-drilled holes where the waste was either allowed to melt down through the ice sheet to bedrock or was maintained to position by surface anchors for an extended period and (2) emplacement in a shielded surface facility which would eventually become buried in the ice sheet.

Concepts for disposal at sea involved emplacing canisters of solidified waste in holes drilled into rock underlying the seabed. Extraterrestrial disposal concepts were based on launching the waste into orbit around the sun. Transmutation concepts considered the use of fission reactors, fusion reactors, accelerators, and nuclear explosives.

The potential for using crystalline rocks at the Savannah River Plant in South Carolina for disposal of radioactive waste was evaluated (Proctor and Marine, 1965; Parker, 1968; and Christl, 1964). The concept was abandoned because of concerns about the overlying regional aquifer.

Subsequently, essentially these same alternatives were considered and analyzed in an environmental impact statement (EIS) that was prepared for the Management of Commercially Generated Waste (DOE, 1980*a*). Such an analysis is required by the National Environmental Policy Act (NEPA) before the adoption of a program strategy for any major federal action. On the basis of the EIS, DOE issued a Record of Decision (DOE, 1981) endorsing geologic isolation as the primary option for disposal of HLW and transuranic (TRU) nuclear waste.

### 3.1.5 The Retrievable Surface Storage Facility (RSSF)

In May 1972, the AEC announced its intention to develop surface facilities for long-term storage of solidified commercial HLW at an undesignated AEC-owned site. This facility would be designed to provide high-integrity containment for more than 100 years, to have minimal operating requirements, and to provide for ready retrievability of the waste canisters when a geologic repository or other suitable disposal method had been developed (Pittman, 1972). The Atlantic Richfield Hanford Company was selected to prepare and to evaluate several storage concepts that would be suitable for this purpose.

Three conceptual designs were developed for a RSSF: (1) a water-filled and water-cooled vault; (2) air-cooled vault; and (3) sealed, shielded casks for each waste canister and passive air cooling. Of these approaches, the sealed-cask concept was selected for further development, and several prototype casks were constructed between 1973 and 1975. Cask tests were carried out at the Hanford site in the absence of radiation and with electric heaters to simulate decay heat, while tests at the Nevada Test Site (NTS) used spent fuel assemblies.

A draft environment statement was prepared by the AEC, and public hearings and written comments followed its release (1974*b*). The RSSF program was sharply criticized because of the perception that it represented a lack of dedication on the part of the AEC to find a solution to the waste disposal problem. This was particularly frustrating to the AEC inasmuch as it had been strongly encouraged to consider an interim storage option, thereby permitting a more thorough examination of disposal technologies on a less demanding schedule. The draft statement was formally withdrawn shortly thereafter. When the AEC was abolished by the Energy Reorganization Act of 1974, its successor organization, Energy Research and Development Administration (ERDA), deemphasized the RSSF concept and instituted an expanded program designed to develop several geologic repositories in a variety of rock types for commercially generated radioactive wastes.

## 3.2 PRINCIPAL ELEMENTS OF THE SITING PROCESS

### 3.2.1 Criteria

Criteria for selecting a site for the demonstration test at Lyons, Kansas (Project Salt Vault), included the availability of an existing, preferably inactive, mine in rock salt, a section of salt that would be representative of that to be used for an actual repository, and favorable public relations at both the state and local levels.

Early considerations in siting the demonstration repository at Lyons, Kansas, were (1) salt deposits in the United States; (2) depth, thickness, and geologic limitations; (3) disposal of excess salt; (4) land values and population centers; (5) waste transportation costs; and (6) public acceptance (Bradshaw et al., 1969). Later in 1971, formalized criteria were developed for this first repository (Culler, 1971). To ensure an efficient operation and to provide maximum assurance of long-term safety for the demonstration repository, it was believed at that time that a salt deposit should meet certain minimum geological requirements. However, it was also felt that those requirements would not necessarily be considered applicable for siting all future repositories because some criteria would almost certainly be relaxed, and perhaps new ones added, as more information and experience were gained from the operation of the first repository. These criteria were among the first to be established and are summarized as follows (Culler, 1971):

1. The salt formation should be bedded approximately horizontal and relatively undisturbed structurally so that the previous R&D work on this disposal concept would be applicable. (This precluded consideration of salt domes which are generically and structurally much different.)

2. The formation should extend a considerable horizontal distance, measuring at least several tens of kilometers.
3. The formation should not be less than 150 m (500 ft) deep or 60 m (200 ft) thick.
4. At the disposal site, the depth to the top of the salt formation should not be greater than 600 m (2000 ft) because of both the increased cost and the increased difficulty of operating at greater depths.
5. The formation should not have associated with it, or be in the immediate vicinity of, potentially valuable reserves of petroleum or other mineral resources.
6. The area should be tectonically stable.
7. The area should contain a deeply buried, permeable formation into which substantial volumes of artificial brine resulting from the dissolving of the excess salt produced during the mine-excavation phase could be injected.
8. It must be possible at least to infer a reasonable measure of geologic information about a specific site in order to evaluate even its preliminary acceptability, pending further detailed investigation. Because of the geologic nature of salt deposits, these inferences could be based on information obtained from either accessible mines in the area or from a rather large number of existing boreholes that penetrate the formation.

In the investigations for alternative demonstration-repository sites in Kansas, use was made of different siting criteria that were developed by ORNL and the KGS, respectively (ORNL, 1972; University of Kansas, 1971, 1972*a*). The criteria developed at ORNL were preliminary in nature and were assembled to serve only as a guide in the selection of a repository site in rock salt deposits within the state of Kansas. The criteria developed by the KGS, on the other hand, were based primarily on safety factors, but they also included some factors relating to cultural and economic considerations as well. Because of the extensive statewide search for supplemental sites in Kansas and the lifting of the earlier requirement that an existing excavation or mine be available for disposal, the criteria used for site selection were more detailed that for any previous efforts.

Other than its location in a "thick and extensive" salt deposit, the only criterion that had been used in selecting the Lyons, Kansas, site was the availability of an existing and accessible subsurface mine. Thus, the generalized and mostly technical site selection criteria that were used to evaluate the supplemental areas elsewhere in Kansas for potential demonstration repositories were the first criteria to be formalized and documented. Although they were promulgated specifically for locating sites in Kansas, these criteria provided a basis for a series of refinements and improvements. This first set of criteria, while incomplete and rather simplistic as compared to those in use today, reflected the state of thought in site selection at that time and were useful in the evaluation of sites in Kansas. Further, they led to the development of criteria that could be used later in selecting potential repository sites in any rock type in any region of the country.

### 3.2.2 Disposal Concepts

The preferred concept for disposal was emplacement of cylindrical containers in vertical holes drilled in the floor of underground excavations. Experimental data on this repository concept were obtained from the Project Salt Vault experiment, where canisters containing spent fuel assemblies were placed in (and later removed from) lined vertical holes in the floor of the Lyons mine.

The Demonstration Repository at Lyons, Kansas, was expected to use the existing 72-ha (180-acre) mine and approximately 360 ha (900 acres) of adjoining properties that were underlain by the Hutchinson Salt (Wellington Formation). In addition, a buffer zone at least 520 m (1700 ft) wide would be established around the periphery of the site through the acquisition of subsurface mineral rights. The repository was to have the ability to store all of the alpha and HLW to be generated in the country through the remainder of the century and would be operated as a "demonstration" repository while verifying all design and operational procedures. The mine was to be designed so that within 60 to 100 years, the salt, by the processes of plastic flow and recrystallization, would have reconsolidated and the wastes would be completely sealed and isolated from the biological environment (Culler, 1971).

The supplemental sites in Kansas were selected as alternative to the Lyons site. The criterion that dominated the selection process for the Lyons site (i.e., the presence of an abandoned mine or cavern in the salt) was not included in the criteria for the supplemental sites. Rather, criteria were added that reflected conditions favorable to the development of subsurface openings capable of safely containing waste at a more reasonable cost. At the same time, the number of alternative areas that could be explored for potential repository sites was greatly increased.

### 3.2.3 Relationships with the States, Indian Tribes, and the Public

From the earlier field experiences at the Hutchinson, Kansas, mine, good public relations had developed among ORNL, AEC, state and local officials, and the general public in central Kansas. This good will was maintained throughout Project Salt Vault. However, some erosion of this relationship became evident with the initiation of cooperative technical investigations related to siting the Demonstration Repository.

In August 1970, the KGS, in cooperation with the USGS, the U.S. Army Corps of Engineers, and the State of Kansas Department of Health, initiated a detailed study of the surface geology, subsurface geology, and groundwater hydrology in a 23-$km^2$ (9 square miles) area centered on Lyons, Kansas. Funding for this program was provided by the AEC, and the work was managed by ORNL. The final report was released as a KGS publication in 1971 (University of Kansas, 1971).

Governor Docking of Kansas and his staff were briefed frequently during the investigative work at the Lyons site. Initially, the Governor took a neutral stance toward the project, but by mid-1971, this changed to a negative attitude. The Governor's altered position arose in part on technical grounds as the result of increasing concerns over the problem of plugging the boreholes near the site, solution-mining operations at the American Salt Mine, and other shortcomings of the site as described by the KGS and others. Political pressure from other elected officials in the state also was a factor, as was probably the stark realization that the nation's first, radioactive HLW repository (which was perceived not to be of significant economic benefit to the state) might soon be permanently located there. However, the local government and population at Lyons remained receptive and supportive of the program.

The evaluation of the supplemental sites in Kansas was conducted almost exclusively by the KGS and the UKCR under subcontract to ORNL. This is significant in that the principal investigators for this early siting study were state agencies. Furthermore, some of the criteria used for comparing sites within Kansas were developed by these same state organizations. This illustrates the commitment by the AEC, even in these early years of the siting program, to directly involve state governments in the technical aspects of siting.

### 3.2.4 Technical Issues

During Project Salt Vault, important new data on technical issues (such as the stability of rock salt at elevated temperatures and the radiolytic production of chlorine) were obtained. No production of free chlorine was detected, bearing out theoretical calculations. The in-situ heat-transfer properties of salt were found to be reasonably close to laboratory-determined values, thus increasing confidence in theoretical calculations of heat transfer in a repository setting. It was also observed that the thermal load resulted in greater rock mechanical stresses as seen in the mine pillars and roof; greater plastic flow in these areas was a coincident observation. This field demonstration also resulted in the major discovery that small inclusions of brine contained in the salt would migrate toward a heat source (Bradshaw and McClain, 1971).

The major concerns that were prevalent during the Demonstration Repository siting work at Lyons were related to the (1) occurrence and distribution of abandoned oil and gas boreholes and (2) the presence of nearby solution-mining operations. The principal threat from oil and gas boreholes that penetrate the salt is the potential for these holes, if they are not properly plugged, to transmit water from formations above or below the salt repository horizon. This condition could lead to rapid dissolutioning of the salt formation and eventual collapse of the overlying formations around such boreholes. On the one hand, the AEC and its investigators were confident that they would be able to locate, clean, and satisfactorily plug any number of boreholes in and near the site. On the other hand, the critics argued that it would be extremely difficult, if not impossible, to give the required assurance that all abandoned boreholes had been located. Furthermore, they contended that adequate guarantees could not be given that the plugs for the holes would remain intact for the required isolation period (NAS and NRC, 1970; University of Kansas, 1971).

The second technical issue at the Lyons site focused on the solution-mining operations of the nearby American Salt Corporation. These mining operations, which consisted of pumping fresh water into injected wells that penetrated the salt formation and withdrawing the resulting brine from those or adjacent wells, extended over an area of about 56 ha (140 acres) and were situated 5 km (3 miles) south of the proposed demonstration repository. The AEC believed that this solution-mining operation did not constitute a threat because of the distance from the repository and the buffer of undisturbed salt between the two facilities. Concerns over the exact location and lateral extent of the solution-mined cavity, the possibility of a volume of water in a related hydraulic-fracturing test project, and related water-infiltration problems caused by old boreholes within the mine proper, collectively contributed to a loss of confidence in the Lyons site and its eventual abandonment (University of Kansas, 1971; Lomenick, 1972).

Several technical issues were prominent in the selection of study areas for supplemental repository sites in Kansas and in their subsequent evaluations. Among those were (1) the thickness, depth, and purity of salt deposits; (2) buffer zones, (3) concentration of boreholes; and (4) salt dissolutioning. Although the relative importance of each issue was not evaluated, the most important concern was the dissolution of the salt beds around abandoned oil and gas boreholes (induced dissolution) and along the eastern edge of the salt formation in central Kansas (natural dissolution). The potential for natural dissolution at the upper and lower subcrop surfaces of the salt formation was also of concern. Implications of this were first recognized during the Kansas site investigations, but little was known about this phenomenon at that time. Even now, with the extensive data that have been accumulated on the subject, a complete understanding of the origin and development of natural dissolution features has not been attained.

### 3.2.5 Participating Organizations

The principal contributors to the Project Salt Vault were ORNL, AEC, and the Carey Salt Company. This combined effort resulted in a highly successful demonstration of the practicality of disposing of solidified radioactive wastes in a salt deposit.

During the course of the site investigations for the Demonstration Repository at Lyons, Kansas, the AEC directed the work and served as the principal contact with the Governor of Kansas and other state officials. UC-NC was the prime contractor to the AEC, whereas ORNL provided technical direction for the work. The U.S. Army Corps of Engineers drilled several test holes within the area, whereas the USGS conducted hydrologic tests in the boreholes. The KGS served as a subcontractor to ORNL for the project, as did several private corporations and expert consultants. At the request of the AEC, the NAS and NRC Committee on

Radioactive Waste Management assisted in the evaluation of the demonstration project at Lyons (NAS, 1957, 1961). In its 1970 report, NAS deemed the Lyons site to be satisfactory, subject to certain caveats and the development of additional confirmatory data and evaluations (NAS, 1970).

The principal investigative organizations responsible for the supplemental repository-site studies in Kansas were the KGS and the UKCR. That work was funded through subcontracts with ORNL. A number of consultants were also employed by the Kansas group to assist in the studies. The USGS participated in the hydrologic testing of the specially drilled boreholes.

# 4. PERIOD: 1973–1975

## 4.1 PRINCIPAL EVENTS AND STUDIES

As had been the case for the two preceding time periods (1954–1961 and 1962–1972), the emphasis in siting investigations continued to be directed at rock-salt deposits. One variation was that salt deposits outside Kansas and the northeastern states received appreciable attention. Another was that Gulf Coast salt domes, in addition to the several occurrences of bedded salt, were studied.

This time period thus represented an interval of transition as evidenced by several developments. Geographically widespread salt deposits were under review, and the first detailed studies of salt domes were in progress by the end of this period. The major focus on bedded salt had also moved from deposits in Kansas to southeastern New Mexico; the original "pilot-repository" concept begun in the latter region persists today, albeit in modified form, as the Waste Isolation Pilot Plant (WIPP), New Mexico . Another transition that was beginning to take form was technical interest in nonsalt rock types as possible waste-disposal hosts. Thus, the initial studies on clay-rich strata, chalk, and granites and other granitoid igneous and metamorphic rocks were begun during this time period. Investigations on these and other nonsalt rocks experienced a considerable expansion within the next time period (1976–1981). This expansion was partly caused by the belief that the siting of repositories in several different sections of the country would be viewed by the states as a fair sharing of the "burden" of hosting a repository and would thus be accepted.

This period also witnessed several noteworthy transitions in a programmatic sense. Following the difficulties of the Lyons demonstration repository, the AEC also experienced some siting problems within southeastern New Mexico related to unexpected geologic conditions there. In proposing retrievable surface storage as a near-term engineering alternative to mined repositories, the AEC faced further and more persistent opposition. Because of concerns in certain political and governmental circles, the AEC was abolished by the Energy Reorganization Act of 1974 in late 1974; responsibility for its waste-disposal programs was transferred to its successor agency, the ERDA, whereas its former regulatory purviews served as the genesis for the NRC. These agencies became operational in January 1975.

These several transitions served as the foundation for continued siting studies. However, new emphasis, expanded programs, accelerated time tables, and additional organizational changes during the next five years further modified the waste-disposal program.

### 4.1.1 AEC Waste Management Study Program—Geologic Storage Alternatives

In view of the uncertainties identified in selecting and constructing a geologic repository at Lyons, Kansas, as well as at any of the eight supplemental study areas located in that state, the AEC enlarged the federal waste-disposal program in March 1972 to include investigations of (a) rocks other than salt and (b) alternative disposal methods. The AEC also made arrangements to use the expertise and capabilities of the USGS in the search for "pilot repositories" As part of a broad program of studies and assessments to investigate high-level and alpha-contaminated wastes. Specifically, the pilot-repository program included investigations of various formations such as bedded salt located outside of Kansas (in particular, the potash-mining area of the Permian Basin in southeastern New Mexico) and other impermeable rock types that might be suitable for the disposal of waste.

The overall objective of this program was to identify specific locations where pilot repositories could be constructed so that in situ demonstrations could be conducted that would confirm evidence of waste-rock compatibility (Pittman, 1972; ORNL, 1972). To accomplish this objective in the time allocated, studies were to be concentrated in areas where the necessary geologic and hydrologic data were already available or could be obtained readily. The tentative selection of sites for these pilot repositories was to be completed by July 1972, while the final selection was to be made 1 year later. This schedule would permit funding for the construction of the first pilot facility by 1980.

Guidance for the evaluation under the pilot-repository program included the following assumptions (ORNL, 1973):

1. The initial repository would be considered as a pilot plant and would be capable of continuously monitoring and maintaining any wastes emplaced within it. All emplaced wastes would be retrievable, at least during the in-site demonstration phase.
2. TRU and HLW could, but need not, be stored in the same repository.
3. Preferential consideration would be given to locations on government-owned sites, whereas special attention would be devoted to sites which, because of previous AEC activities, would probably remain under close government control for long periods of time.
4. Surface-handling facilities would be essentially the same for any type of geologic storage and would follow the concept developed for the Lyons project.
5. The size, shape, weight, heat content, and other characteristics of the waste containers and shipping casks as well as the physical characteristics of the contained HLW would be the same as those for the Lyons project.
6. Sufficient data on the location selected for the pilot plant would have to be available to enable preparation of a preliminary safety analysis report by June 1973, and a completed draft environmental impact statement (EIS) by November 1973. The EIS requirement was a direct result of the then recently enacted NEPA.

### 4.1.2 Southeastern New Mexico

Although the AEC's Geologic Storage Alternative Program prompted investigations of several basins that contain rock salt, and of even other rock types, it was clear, even in the early stages of the project, that southeastern New Mexico was one of the preferred locations for a pilot repository because of the abundance of geologic data already accumulated by the USGS on the potash-mining area there and the federal ownership of much of the land. The presence of abandoned potash mines and the seemingly favorable sociopolitical characteristics of this region also contributed to this recognition. In general, the investigations proceeded from broad, regional, literature-review studies to specific-area evaluations. The latter included exploratory boreholes and geophysical surveys used to define subsurface geologic and hydrologic conditions.

Four large areal tracts, three in southeastern New Mexico and one in the east-central part of the state, were studied in some detail following their identification from the regional-review phase. The former included the Carlsbad potash, Mescalero Plains, and Los Medaños areas, whereas the latter involved the Clovis-Portales area to the north. The Salado Formation was the principal salt-bearing unit in the more southeasterly areas, whereas several older salt-bearing formations, such as the Seven Rivers and San Andres formations, were of possible interest in the Clovis-Portales area.

#### 4.1.2.1 The Carlsbad potash area

The first investigative siting work in southeastern New Mexico consisted of a literature review of the available geologic and hydrologic information about the potash mines and the surrounding terrain in the so-called Carlsbad potash area. Much of this information had originally been compiled by the USGS during its earlier studies on the potash resources of the Carlsbad district. This literature review pointed out that a very thick (>305m) sequence of gently dipping (less than two degrees) beds of rock salt and associated evaporite strata underlie this semiarid area of low topographic relief (Brokaw et al., 1972).

As a second step in the siting study of southeastern New Mexico, the USGS was funded by ORNL to supplement its earlier work with a more detailed study of the geologic, lithologic, and hydrologic characteristics of the Los Medaños area (Jones, 1973). This area, smallest of the four studied, actually overlapped with the southeasternmost corner of the Carlsbad area. A surficial geologic map was complied on a four-township area (approximately 144 square miles) a few miles southeast of the potash mines. The stratigraphic and structural characteristics and the mineralogy and petrology of the evaporite units were also determined. With the use of these data and information from two deep (≈900m) core holes, a tentative site for a potential pilot repository was identified near the center of this four—township area. This site was located some 30 miles due east of the City of Carlsbad.

In order to provide a possible alternative to the salt deposits of the Salado Formation in the Carlsbad potash area and the Los Medaños site, the bedded salt sequences beneath the Clovis-Portales and Mescalero Plains areas of east-central New Mexico were also studied by the USGS for ORNL (Jones, 1974*a,b*). Using data from geophysical and lithologic logs of boreholes and published records, the USGS concluded that thick beds of rock salt were present in these areas at depths in excess of 305 m (1000 ft). Salt of Salado age was present under the Mescalero Plains, but was shown to be thinning in a northward direction (Jones, 1974*b*). However, because of widespread dissolutioning of the salt and the lack of closely spaced, more definitive subsurface stratigraphic and structural data, these areas were not considered as promising for a pilot repository as the other two areas farther to the south.

#### 4.1.2.2 Salt deposits of the Paradox Basin

A summary and background study was carried out by the USGS for ORNL on the salt deposits of the Paradox Basin in southeastern Utah and southwestern Colorado. Although thick deposits of rock salt were found to underlie 31,200 $km^2$ (12,000 $mile^2$) in this region, the USGS concluded from this study that most of the deposits occurred at depths greater than 1500 m (5000 ft) and that potentially suitable deposits of salt probably would be found only in a series of salt-cored anticlines located along the northeastern side of the basin (Hite and Lohman, 1973).

### 4.1.3 Siting for a Pilot Repository in Other Salt Deposits and Non-Salt Rocks

In March 1972, the AEC instructed ORNL to search for pilot repository sites in bedded salt deposits outside of southeastern New Mexico, salt domes, salt-cored anticlines, and other impermeable rocks such as shale (Pittman, 1972). In particular, investigations on rock salt focused on salt domes in the Gulf Coast region, on the thick salt of the Luke Body in central Arizona, and on the bedded salt of the Supai Basin in eastern Arizona. The salt deposits contained within anticlinal structures of the Paradox Basin in eastern Utah and western Colorado were considered, along with bedded-salt formations in the Panhandles of Oklahoma and Texas. Other bedded-salt deposits were studied in the Appalachian Basin of New York and Ohio, in the Michigan Basin, and in the Williston Basin of Montana and North and South Dakota.

Investigations were initiated on argillaceous or clay-rich rocks because of their general impermeable nature, great thickness, and widespread distribution. Brief summaries of the findings from these studies are presented in the following sections.

#### 4.1.3.1 Salt domes in the gulf coast region

The USGS was commissioned by ORNL in early 1972 to summarize the available pertinent geologic and hydrologic data on the salt domes of the Gulf Coast region. These background data were assembled as the first step in the evaluation of these salt structures for the emplacement of HLW. A product of the USGS study was a report (Anderson et al., 1973) that concluded that 36 of the 263 known and inferred onshore salt domes in Texas, Louisiana, Mississippi, and Alabama, were considered to be potentially suitable for the disposal of wastes. The report further summarized the geology and hydrology of the entire Gulf Coast salt-dome province and presented data on the size, shape, depth, and location of the 36 cited domes.

#### 4.1.3.2 Salt deposits of Arizona

An open-file report was issued by the USGS in 1973 summarizing investigations of the two most extensive and known salt deposits in Arizona (Mytton, 1973). These preliminary studies, which summarized readily available geologic and hydrologic data on the Luke Salt Body and the Supai Salt Basin, were sufficient to dismiss them from further consideration. The close proximity of the Luke Salt Body to Phoenix and dissolutioning of the salt within the Supai Formation along the southwestern part of the basin were the principal liabilities of these deposits.

#### 4.1.3.3 Salt deposits of the northeastern states

A literature study of the salt deposits in the northeastern states was prepared by ORNL in 1972 by K. K. Landes (Landes, 1972). In this report, it was concluded that, because of depth restrictions, beds of salt potentially suitable for a repository were present only within the Salina Group in parts of the Michigan Basin (Michigan) and the Appalachian Basin (New York and Ohio). Using maps showing the thicknesses and depths of the salt deposits along with certain environmental factors and other data, a number of prospective areas for a pilot repository were identified. Optimal conditions for a prospective area included (Landes, 1972):

1. A feasible, minable salt thickness [4.5 m (15 ft)].
2. Depth preferably less than 600 m (2000 ft), but a few tens of meters more might be acceptable in areas that have not been subjected to lateral compression.
3. The salt layer to be mined must be overlain and underlain by impermeable strata having enough individual thickness to block off any water flows from aquifers in the stratigraphic section.
4. The roof must be strong enough to maintain a ceiling, preferably without roof bolting, after a storage room has been mined.
5. The floor should not be plastic enough to heave.
6. There should be no petroleum-bearing strata in the immediate vicinity.
7. Brine galleries produced by nearby solution mining of the same salt beds were to be avoided.
8. The number of boreholes drilled through the salt section were to be kept to a minimum. Old drillings, without adequate plugging and with hazy locations, were to be avoided.
9. The lowest population density was a desirable goal.
10. Public recreation areas were to be avoided.
11. The site must be located near either navigable water or a railroad (preferably both).
12. The tract should be large (preferably with a single owner). Land acquisition of small parcels from separate owners was viewed as extremely difficult.
13. Both preexisting salt mines and newly mined space intended exclusively for radioactive-waste disposal were considered as equally acceptable.

These requirements are generally similar to the siting criteria and factors that had been developed earlier by ORNL for the work in Kansas.

Although the Landes report (1972) provided good background data for siting in the northeastern states, the next investigations did not take place until 1976 (Landes, 1976*a*; 1976*b*). Further studies were undertaken in these basins during subsequent siting programs (see Appendixes G and I).

#### 4.1.3.4 Shale, mudstone, and claystone

Shale and other clay-rich rocks and deposits were also considered potentially viable hosts for waste-disposal because they are abundant, thick, geographically widespread, and exhibit favorable properties such as impermeability and good radionuclide-retardation potential. In light of these considerations, a general review of thick shale-mudstone-claystone bodies in the conterminous United States was undertaken by the USGS for ORNL in 1972. In the following year, a report of findings was issued which provided background data on such things as the depth, composition, permeability, structural and seismic history, and extent of drilling in these rocks (Merewether et al., 1973). The USGS investigators concluded that shales, mudstones, and claystones there were of marine origin and located in areas of slight or no structural deformation and minor seismic risk were the most promising for further study. The low permeabilities, high plasticities, large ion-exchange capacities, and widespread distributions of argillaceous rocks were cited as desirable characteristics regarding disposal in these rocks. The copious quantities of swelling clay minerals and organic matter were determined to be undesirable properties. More-detailed siting studies in shale and related rocks did not follow this work immediately, but investigations of the Pierre Shale, which underlies a large part of the upper midwestern part of the country, were initiated by the USGS in 1974 (Shurr, 1977).

### 4.1.4 Geologic Disposal Evaluation Program (GDEP)

GDEP was created at ORNL in early 1974 under the auspices of the AEC and was subsequently directed from late in that year onward by ERDA. GDEP developed a small centralized nuclear waste management group to direct a comprehensive nationwide site-investigation program. The stated objectives of the GDEP were to (1) evaluate the suitability of all potential geologic formations and rock types as permanent disposal repositories for liquid, solid or TRU radioactive waste, using appropriate emplacement technique and (2) carry out in an orderly manner those R&D activities that could lead eventually to the establishment of waste-disposal repositories using one or more of the promising isolation systems developed (McClain et al., 1975).

The first phase of the GDEP called for an investigation of the general properties and fundamental characteristics of various rocks to identify the types of rock formations that might be suitable for waste disposal, without reference to either the waste type or emplacement technique. At the same time that the characteristics of various rock types were being catalogued, the feasibility of various emplacement concepts were being evaluated without reference to rock type. These evaluations were based solely on engineering feasibility using existing technology. Criteria for acceptance limits in rock properties and in emplacement technology were to be developed. The intention of this approach was to bring together the information obtained by independent evaluations to identify the most-promising combinations of rock types, waste forms, and emplacement concepts. Each such combination was described as a waste-disposal system.

The GDEP effort was divided into three major tasks: (1) geologic and hydrologic investigations; (2) developmental studies; and (3) engineering assessment studies. Geologic and hydrologic investigations were concerned with the general characteristics, features, and occurrence of various rock types and the evaluation of their suitability as waste repository hosts. Developmental studies provided information necessary to support both geologic and hydrologic studies and the engineering assessment studies. Engineering assessment studies were concerned with evaluating alternative waste disposal systems and carrying out the necessary R&D efforts so that promising concepts could evolve into acceptable practical measures.

The GDEP site investigations (see Appendix B) included bedded-salt formations in southeastern New Mexico, salt domes in the Gulf Coast region, salt-cored anticlines in the Paradox Basin of southwestern Colorado and southeastern Utah, existing storage caverns in various types of rocks, including granite, shale formations in the Great Plains states, mid-continent limestone formations, chalk deposits in the southeastern states, volcanic rocks in the western states, and several different igneous and metamorphic rocks (later studies would refer to many of these rocks as "crystalline rocks") in various locations throughout the county.

## 4.2 PRINCIPAL ELEMENTS OF THE SITING PROCESS

### 4.2.1 Criteria

AEC's exploration for suitable sites for a pilot repository included the following major nontechnical criteria (Pittman, 1972): (1) the selection of locations where geologic and hydrologic information was already available or could be gathered quickly; (2) preferential consideration was to be given to locations on government-owned land; and (3) sufficient data must be available on the selected location to provide a Preliminary Safety Analysis Report by June 1973 and a complete draft EIS by November 1973. Although the first two criteria were not relaxed, the third criterion, on scheduling, was changed on many occasions to accommodate delays in gathering the necessary site-characterization data. Adding to these delays were changes in federal policy for the waste-management program. The first scheduling delay occurred in 1973, and additional changes in the schedule for constructing the facility (eventually renamed amid some site-location changes as the WIPP) have occurred.

Initial technical criteria for site selection for the pilot repository in southeastern New Mexico closely followed the criteria established for the Kansas sites (see Sect. 3.2). In 1973, ORNL issued a list of geographic, geologic, and socioeconomic criteria and factors to be considered in selecting potential sites (ORNL, 1973) for the pilot repositories. These criteria, which were endorsed by the AEC, were used to select the first potential site in the Los Medaños area for a pilot repository in southeastern New Mexico.

The first definitive statement of generic siting criteria originated at the outset of the GDEP (Piper, 1974). In this work, the principal characteristics required for the deep placement of HLW required a rock to (1) be unweathered and distinctly homogeneous, (2) have no more than nominal intergranular pore space, and (3) be nonslaking. Other rock characteristics that might influence the design or affect the operation of a waste repository, but ordinarily would not be definitive, were the rocks density, strength, elasticity, thermal conductivity, solubility, chemical reactivity, and magnitude and orientation of residual stress (Piper, 1974).

Three criteria for the hydrologic setting were also provided: (1) nominal hydrologic conductivity, (2) hydrologic isolation of the repository horizon; and (3) long-term effectiveness of the system to withstand the effects of possible geologic or climatic changes.

### 4.2.2 Disposal Concepts

Initially, the disposal method proposed for a pilot repository was the same as that envisaged for the Lyons, Kansas, demonstration repository. This plan called for the disposal of TRU contaminated waste (alpha-contaminated) into an adjacent inactive salt mine on the same mining level and a specially excavated facility in which canisters of heat generating HLW would be emplaced (Martin, 1972). The canisters would be buried in the floor, and all wastes would be retrievable at least during the in-situ demonstration phase. After it was determined in late 1972 that existing, but abandoned, potash mines in southeastern New Mexico could not be used for the pilot repository because of the remaining reserves of potash, the disposal method was revised to include storage of alpha-wastes in newly excavated underground space. A further revision was made to the method proposed for disposal at the pilot repository in New Mexico in August of 1974, at which time the AEC directed that this facility would be modified in order to serve as an "interim alpha-waste repository" (Schreiber, 1974). This modification, the surface facilities, and the underground workings would be changed to accommodate the disposal of alpha-contaminated wastes (largely defense-related wastes) and fuel hulls.

Along with site investigations, GDEP examined several potentially promising concepts in order to develop them into workable waste-disposal techniques. The engineering assessment studies on disposal methods were carried out under five broadly defined programs: (1) characterization of wastes; (2) analysis of techniques for emplacing gaseous, liquid, or solid wastes in a geologic formation; (3) repository design; (4) development of promising waste disposal systems, and (5) evaluation of waste-disposal systems (McClain, et al., 1975).

**4.2.3 Relationships with States, Indian Tribes, and the Public**

In the siting investigation for a pilot repository in New Mexico, the AEC made special efforts to ensure that the state and local governments, as well as civic groups and other interested parties, were briefed on all policy developments toward establishing a repository there. One of the first such briefings was at a conference hosted by the New Mexico Department of Development in where the Director of the AEC's Division of Waste Management and Transportation presented plans for the selection of a pilot-plant repository in that state. At the conference, entitled "The Future Role of New Mexico in Nuclear Development," attendees included the Mayor of Carlsbad, the County Commissioners, representatives of the State Environmental Improvement Agency, and the New Mexico Bureau of Mines and Mineral Resources, and individuals and representatives of other organizations.

Although Sandia National Laboratory (SNL) was the lead contractor on the New Mexico studies and the USGS was a leading investigator in southeastern New Mexico, the New Mexico Bureau of Mines and Mineral Resources was also active, especially in the evaluation of oil and gas resources. The University of New Mexico at Albuquerque and the New Mexico School of Mines at Socorro were cooperatively involved by virtue of specialized research studies undertaken at the request of the AEC.

The GDEP approach to siting investigations was to use a diverse group from a broad range of disciplines to resolve technical questions. The assistance of state agencies was encouraged for many of the technical investigations. For example, in the Permian Basin of New Mexico, the New Mexico Institute of Mining and Technology and the New Mexico Bureau of Land Management conducted the investigations to identify sites for stratigraphic test holes. They monitored the oil and gas exploration activity in the region in order to identify boreholes that might eventually have to be plugged to preserve the integrity of any identified site. The state work was integrated with activities conducted by the USGS and private consultants.

In a similar manner, the Colorado School of Mines participated in investigations of the Pierre Shale and provided liaison with state agencies. Investigations of the Gulf Coast salt domes were undertaken simultaneously by research groups at the University of Texas and at Louisiana State University (LSU). The Engineering Mechanics Research Laboratory of the University of Texas at Austin conducted a review of salt domes in the Gulf Coast Region; it was designed to (1) identify the location of candidate domes; (2) determine the tectonic stability of the region; (3) examine the hydrologic integrity of identified domes; (4) determine the geometry of identified domes, and (5) address the subject of residual stress within the domes (Ledbetter et al., 1975). While this regional study was under way, the Institute of Environmental Studies at LSU began work to determine (1) the tectonic stability of salt domes in general; (2) the hydrologic stability of domal structures; and (3) the precise sizes and shapes of certain key domes (Martinez et al., 1975). Concurrent with their technical investigations, these state university research organizations served as liaisons between state governments and the national waste program.

### 4.2.4 Technical Issues

Technical issues considered in siting studies for the pilot plant repositories included regional tectonics and seismicity, thickness, purity, and depth to the salt beds, and the occurrence and characteristics of ground and surface waters. However, the issues of greatest concern were the distribution of potash minerals within the salt beds, the oil and gas potential of the deep underlying rocks, and the phenomenon of salt dissolution. These issues were thoroughly considered, and, even though a great amount of study was necessary to resolve them, it was ascertained that none of these factors would preclude the siting of a repository in southeastern New Mexico. However, several changes in location of the site and in orientation of proposed workings for the pilot repository were made in response to the presence of nearby recently drilled oil and gas boreholes, the encountering of pressurized brine pockets at depth, and subsurface strata that were distorted due to dissolution and proximity to the underlying Capitan Reef, (Battelle, 1979).

The key technical issues of GDEP were the identification of the rock type and the waste emplacement technique that could ensure isolation as an integrated waste-disposal system. Also of significance during this time period were the technical issues raised by the programmatic competition between waste disposal or storage based on a mined geologic repository and an engineered, above-ground facility, the RSSF. In fact, some geologic field investigations were markedly delayed as the result of a shift in technical emphasis to the RSSF. The eventual demise of this non geologic facility, the RSSF, is attributable to societal and political pressures that arose from concerns that adoption of the RSSF would mean that no permanent disposal would ever be implemented or would unfairly shift the responsibility for disposal to subsequent generations.

### 4.2.5 Participating Organizations

The Division of Waste Management and Transportation of the AEC managed the siting work in southeastern New Mexico, with ORNL as the prime contractor. The USGS, subcontractor to ORNL, was the principal geotechnical investigator for siting. The University of New Mexico, the New Mexico School of Mines and Technology, and the New Mexico Bureau of Mines and Mineral Resources were active participants in the work. Several consultants aided in the siting investigations, and the local potash mining companies cooperated fully in all phases of the work.

Throughout the GDEP, the Committee for Radioactive Waste Management of the NAS conducted technical reviews. In addition, the practice of reviewing a program through the establishment of independent ad hoc peer review groups was initiated during this period (McClain et al., 1975). This practice was ultimately followed, with various modifications by the many organizations responsible for subsequent siting studies (see Sect. 5.2.5).

# 5. PERIOD: 1976–1982

## 5.1 PRINCIPAL EVENTS AND STUDIES

From the transition events of the early to mid-1970s, the repository-siting effort emerged under the direction of the federal agency, ERDA, and under the technical direction of a new organization headquartered at Oak Ridge, Tennessee, named the Office of Waste Isolation (OWI) of Union Carbide Corporation—Nuclear Division, and with ambitious plans for expanded siting investigations, enlarged studies of nonsalt rock types, and a greatly accelerated schedule by which to site, construct, and operate several waste-disposal repositories. However, this period (1976–1982) also experienced several significant changes that directly and indirectly exerted profound influences on the disposal program for radioactive HLW. The greatest changes during this period were of policy and of programmatic organizations:

1) ERDA announced the National Waste Terminal Storage (NWTS) Program;
2) President Carter banned indefinitely the commercial reprocessing of spent fuel because of concerns regarding the proliferation of nuclear materials for nonpeaceful applications (Carter, J. E., 1978). This led to the once-through fuel cycle and the disposal of spent fuel;
3) ERDA was replaced by a new Cabinet-level federal agency DOE;
4) NWTS Program was subdivided into three separate technical projects each one focussing on a different rock type (tuff, basalt, and salt). During these significant changes, considerable advances were made in siting studies, refinements of siting criteria, the development of siting criteria, and the development of disposal methodology to accommodate the possible disposal of spent-fuel assemblies instead of solidified reprocessing wastes.

The late 1970s were a turbulent time in U.S. energy affairs, and President Carter urged the establishment of a cabinet-level DOE. Congress responded to his April 1977 energy-policy statement by passing the enabling legislation, the Department of Energy Act, whereby ERDA and other federal energy agencies (e.g. the Federal Energy Administration) were merged to create DOE. The federal waste-disposal programs became the responsibility of this new agency in October 1977. By this Act, the regulatory and licensing activities were taken over by the newly created NRC.

When DOE was activated in October, 1977, Under Secretary Myers directed that a Task Force be formed to review all nuclear waste management programs and to make recommendations leading toward the formulation of an Administration policy. The report of the task force, which was directed by John M. Deutch, was released in February 1978 (DOE, 1978). Commonly referred to as the "Deutch Report," the report included an assessment of the then-current nuclear waste management programs, an identification of important outstanding issues, and discussions of alternative courses of action for proceeding. Among the findings which were highlighted as most significant for management of waste were:

1. A majority of independent technical experts have concluded that HLW can be safely disposed of in geologic media and that validation of the specific technical choices will be an important element of the licensing process.
2. Reprocessing is not required for the safe disposal of commercial spent fuel.
3. Consideration should be given to an early demonstration of the geologic disposal of a limited number of spent-fuel assemblies in WIPP.
4. The Spent Fuel Policy announced by President Carter in October 1977 must be integrated with the Waste Management Policy.

5. A study of the importance of away-from-reactor storage compared to what occurs between on-site storage of spent fuel at utilities and ultimate disposal.
6. The NEPA process is an essential part of the nuclear waste management program, and DOE efforts in this regard must be strengthened.
7. Policy and responsibility for waste management should be raised to a higher level in DOE.

In addition, the report emphasized the need for technical conservatism and recommended (1) that studies of several rock types should continue through the R&D phase (2) that more than one site should be examined for any given rock type and (3) that more than one design concept should be considered for each rock type. Although such a program was acknowledged to be more expensive and lengthier than one exclusively pursuing a predetermined single approach, in the end it might be both more credible and more successful.

Considerable influence was exerted on the direction and focus of the waste-disposal program as the result of (1) increased interest in the siting potential at two federally controlled (by DOE) tracts (Hanford, Washington, and the NTS); (2) several developments in foreign nations where considerable interest was being shown in non salt rock types especially in granites in the Swedish program; and (3) the far-reaching studies and recommendations of a special Presidential advisory board called the Interagency Review Group (IRG) on Nuclear Waste Management. As a result, the original NWTS program was restructured in mid-1978: the study of basalt at the Hanford Site became the Basalt Waste Isolation Project (BWIP), and the studies of several rock types (i.e., argillite, granite, and tuff) at the NTS became the Nevada Nuclear Waste Storage Investigations (NNWSI) (Battelle, 1979). The remainder of the NWTS program was managed by ONWI, their program initially concentrated on lands not directly under the control of DOE, namely those places where rock salt was the potential host. Crystalline rocks were included as an additional component of a redefined ONWI program; thus, by the end of this period, ONWI was responsible for siting studies both in rock salt and crystalline rocks.

### 5.1.1 Interagency Review Group

On March 13, 1978, President Carter established an Interagency Nuclear Waste Management Task Force, composed of representatives of 14 federal agencies, to formulate recommendations for a national policy for long-term management of nuclear wastes and to develop the programs needed to implement their recommendations. The IRG created a Technical Advisory Committee to assist it in developing and analyzing alternative strategies for the disposal of high-level and TRU wastes. In the course of its studies, the IRG obtained a broad range of views from many sources, including Congress, state and local governments, Indian nations, industry, the scientific community, public interest and environmental organizations, and the public.

In its final report of March 1979, the IRG included the following recommendations for repository siting (IRG, 1979):

1. Program activities should be based on the assumption that the first disposal facilities will be mined repositories. Deep-ocean sediments and very deep boreholes were seen as near-term alternative approaches; transmutation, rock melting, and space disposal were judged to be more distant options because of the technical and institutional problems that would have to be overcome.
2. Near-term R&D and site characterization programs should be designed so that sites to be selected for location of a repository could be chosen from among a variety of host rocks and geological characteristics.
3. A number of potential sites in a variety of geologic environments should be identified. The option should be created to have at least two repositories operational within this century and, insofar as technical and other considerations permit, in different regions of the country. In pursuing a regional

approach to siting, geologic, hydrologic, tectonic, and other technical characteristics of sites and safety considerations must remain the major basis for site selection.

4. Construction and operation of a repository should proceed on a technically conservative, stepwise basis and permit retrievability of the waste for some initial period of time.

The IRG report met with a generally favorable reception in both government and public sectors. Its recommendations affected both DOE's repository siting program and the subsequent formulation of the NWPA of 1982.

**5.1.2 Recommendations of Comptroller General and of the Congress.**
The Comptroller General and the Congress urged DOE to consider already-contaminated nuclear sites as candidates for a repository. The Comptroller General's recommendations were to the Chairman of the Subcommittee on Energy, Nuclear Proliferation, and Federal Service (Comptroller General, 1979). The Comptroller General's report (1) pointed out responsibilities of DOE, the U.S. Environmental Protection Agency (EPA), and NRC (2) concluded that past efforts to solve the waste problem failed because of public and political opposition rather than technical reasons (3) summarized the conclusions and recommendations of the President's IRG (4) urged that, before a repository site is selected, DOE should give first consideration to determining if any of the existing highly contaminated federal nuclear reservations are acceptable (5) recommended that the Congress should create a federal and state committee responsible for developing a national waste-management plan (6) pointed out that DOE already is conducting studies at the Hanford Reservation in Washington and at the NTS.

At about the same time as the previously described events were taking place, the NRC issued a Notice of Proposed Rulemaking regarding its confidence as to whether methods of safe disposal of nuclear waste would be available when they were needed. This rulemaking, commonly referred to as the Waste Confidence Rulemaking, is described in Appendix C.

It is noteworthy that by the late 1970s, all combinations of rock type and tracts of land that eventually would lead to the nomination in 1986 of nine sites for the first repository were already being investigated. Therefore, in spite of the many changes and redirection of effort, the waste-disposal program that existed at the end of this period began to assume a clearer image of that which would lie ahead in the next 7 years.

**5.1.3 National Waste Terminal Storage Program**
In February 1976, ERDA redirected and greatly expanded its program for the management of defense and commercially generated radioactive wastes. The commercial geologic waste disposal program, that is, the GDEP, was reorganized as the NWTS program, and the responsibility for NWTS was assigned to ERDA's Oak Ridge Operations Office.

**5.1.3.1 Office of Waste Isolation.**
In March 1976, a special entity called the OWI was created by Union Carbide Corporation-Nuclear Division to direct and manage NWTS management activities for the Oak Ridge Operations Office. All geologic disposal work which had previously been under the management of ORNL was transferred to OWI (OWI, 1976*a*). One exception to this was the disposition of a pilot-repository program in southeastern New Mexico. This program was now clearly designated as the WIPP and had evolved by this time to a commitment dealing principally with the storage or disposal of high-level and TRU wastes generated in the defense program. Management and technical responsibility for this site had been assigned to the Albuquerque Operations office of ERDA at Albuquerque, New Mexico, in late 1975.

The ERDA program was viewed by many observers as extremely ambitious. It directed that as many as six geologic repositories would be sited and constructed. The initial two repositories would be developed in salt and were intended to begin pilot operations as soon as 1985. The remaining four repositories would be built in other rock types, such as shales or crystalline rocks[1] and would be operational by the mid-1990s.

As a reflection of the expanded program and accelerated schedules in late November 1976, ERDA sent letters to the governors of 36 states in which efforts to search for repository sites were planned. This planned expansion was partly because of the belief that the siting of repositories in several different sections of the country would be viewed by the states as a fair sharing of the "burden" of hosting a repository and therefore, would be accepted. However, this significant expansion of the siting program, with its inclusion of a number of states that had not been previously involved, caused an unexpected political furor. This, coupled with other events, such as forecasts of reduced or deferred volumes of waste resulting from cancellation or deferral of planned nuclear-power stations because of reduced power needs and inflated costs, led to a rather rapid demise of this ERDA initiative. However, after this aborted effort, increased interest grew in the potential of the Hanford site and the NTS as possible repository-site candidates.

The objective of the NWTS program was "to provide facilities in various deep geologic formations at multiple locations in the United States which could be used to safely dispose of commercial radioactive waste, which must be delivered to a federal repository for terminal storage" (OWI, 1976*b*). OWI was to manage the development and operation of federal repositories from the time the search for sites began, through facility design and construction, and during the operating lifetime of the repository (OWI, 1976*b*). The objectives of OWI's site/rock investigations were to investigate the general characteristics, features, and occurrences of a number of rock types so that their fundamental suitability for use as emplacement receptacles for radioactive waste could be evaluated (OWI, 1976*b*). The general NWTS exploratory and development sequence consisted of (1) identification of formations of interest (2) reconnaissance to provide geologic data (3) area studies, (4) detailed confirmation studies (5) in situ tests, and (6) repository operations. The particular characteristics to be examined related to the (1) stability of the rock for short-term waste emplacement operations, (2) long-term stability for preservation of waste isolation for periods of hundreds to thousands of years, and (3) tightness or isolation of the area from groundwaters. The latter is premised on the assumption that the most likely release scenario and migration of the radionuclides to the human environment will be via the groundwater. The concept of a systematic investigation from general to specific (i.e., from region to area to site) which had begun to take form in the prior GDEP was further refined.

The plan for siting investigations was stated (OWI, 1976*b*) as follows:

> "First, a regional or basinal reconnaissance study is undertaken to determine if areas exist in a region where the rock unit being considered (1) has at least the minimum thickness necessary for a storage facility (2) does not exceed the maximum depth for optimal emplacement (3) is not within the affected range of regional tectonics and seismicity that exceed allowable limits (4) has favorable hydrologic characteristics and (5) contains negligible quantities of valuable mineral resources (principally oil and gas). If these considerations are met in some areas within that region, then phase 2 would be an evaluation of those areas for such variables as geologic stratigraphy and structure, groundwater, and surface-water hydrology, erosion, tectonics and

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[1] Although ERDA originally included basalt lavas and quartzite, this term has gradually been accepted as referring to certain igneous and high-rank metamorphic rocks rich in silicate minerals whose grain size is sufficiently coarse such that individual minerals can be distinguished with the unaided eye; this is in keeping with general geologic usage of the term.

seismicity, and mineral resources. This phase of the study would entail the gathering and interpretation of pertinent data from well logs, cuttings, cores, etc. that would help to identify subsurface stratigraphy and structure. In addition, the available geophysical surveys, such as seismic, magnetic, and gravity surveys, should be examined. Additional cores, logs, and geophysical surveys may be necessary at this time to adequately define the geology and hydrology of an area. Surficial geological features are also of interest, especially the occurrence and depths of unconsolidated deposits. The present oil and gas fields within the area must be accurately defined, and the potential of the study area for future oil and gas development ascertained. The fluid-bearing character of the rocks from the land surface to at last a few tenths of meters below the rock unit must be defined. Also, surface waters must be characterized according to such criteria as recharge and discharge, base flows, quality, and utility. If the results of the study area investigations suggest that further work be performed in a particular area or potential repository site, the third phase of investigations would begin. This phase would include a very detailed geological and hydrological evaluation of the localized area. At this time, extensive coring and logging will be necessary to determine the mineralogy, stratigraphy, and hydrology of the rock unit. Also at this point, in situ engineering studies of mechanical and thermal stress behavior and other rock properties will be made. Fluid and ion migration studies in the particular rock unit may be necessary."

Siting investigations conducted by OWI involved (1) salt domes of the Gulf Coast Interior Basins in Louisiana, Mississippi, and Texas; (2) bedded salt of the Permian Basin in New Mexico and the Panhandle of Texas; (3) salt-cored anticlines of the Paradox Basin in Utah and Colorado; (4) bedded-salt deposits of the Appalachian and Michigan Basin in New York, Ohio, and Michigan; (5) crystalline rocks; and (6) other rocks. Included in the latter are the basalt lavas at the Hanford Site in Washington, the Eleana Formation at the NTS (work on the volcanic tuffs at NTS did not commence until after mid-1987), and other argillaceous rocks in several parts of the country (see Appendix D for further discussion).

**5.1.3.2 Office of Nuclear Waste Isolation.**

From the late 1950s to 1978, the centers of R&D for the NWTS were in Oak Ridge, Tennessee; Hanford, Washington; and Los Alamos, New Mexico. Projects were developed at these research centers to solve the problems of disposing of defense wastes being created at these facilities beginning at the time of World War II. Over time, ORNL had become the center for investigations applicable to commercial waste. However, early in 1978, the prime contractor for ORNL withdrew from the commercial-waste program. DOE then selected Battelle Memorial Institute of Columbus, Ohio, as the prime contractor to manage the NWTS. Battelle responded to its selection by establishing a new organization called ONWI.

At the time of this transition, the NWTS had evolved into three separate, but coordinated, efforts to identify repository sites. The BWIP examined basalt flows at the Hanford Site in Washington; the NNWSI program examined several rock types at the NTS); and ONWI studied salt and other sedimentary rocks and crystalline rocks throughout the conterminous United States. At the outset, ONWI's program centered on siting studies in bedded and domal salt, but later the program was expanded to include argillaceous and crystalline rocks.

Studies of the southeastern United States were conducted by subcontractors of the Savannah River Plant as part of ONWI's program. Those studies were designed to designate areas that, from a geotechnical standpoint, offer a potential for field exploration to investigate their site-specific characteristics and suitability for nuclear-waste disposal. Rocks and deposits studied were igneous and metamorphic rocks of the Piedmont, sand and clay of the Coastal Plain, and mudstone and shale of the Triassic basins from Maryland to Georgia. Results of this reconnaissance were presented in the following reports published in

1980: [Acres American, Inc.; Bledsoe and Marine; Brown; Butler; Dames and Moore, Inc.; Ebasco Services, Inc.; Secor, Jr.; and Wenner and Gillon (1980)].

From 1978 to 1983 the siting investigations that were originated at ORNL were pursued with great intensity as well as with some refinement by ONWI. It was also a period in which the U.S. energy policy encouraged exploitation of fossil fuels, development of solar and other energy technologies, and conservation as a means of ensuring energy independence. Moreover, it was recognized that any increased contribution from commercial nuclear power would depend upon demonstrating a solution to the problem of disposal of radioactive waste. Contemporaneous with the urgent effort to develop the country's energy resources was the often conflicting need to ensure protection of the environment by developing technologies for dealing with the waste by-products of energy production. In addition to this greater awareness of environmental protection, the only observable distinction between the OWI and ONWI programs was the initiation of a rudimentary quality assurance (QA) program in the latter.

For the most part, the concluding phase of OWI and the beginning phase of ONWI differed little. All of the rock types whose studies had been initiated by OWI continued to be investigated for geologic repositories under ONWI program.

ONWI procedure for identifying suitable repository sites was "based on a series of increasingly detailed studies to obtain geologic and environmental data. The scope of the studies narrowed from regions to areas and then to specific locations. The screening procedure (shown in Figure 5.1) took the following steps: (1) selection of a suitable geologic system for a waste repository through national survey and screening with existing data; (2) determination and further study of regions with such systems; (3) recommendation of specific areas for further study; (4) decontamination of specific locations; (5) recommendation of preferred repository site(s); and (6) detailed site studies (Battelle, 1979). Because the size of a salt dome constrains the size of the area of concern the study of salt domes bypassed the region, and area phases began (after national screening) at the location phase.

## 5.2 PRINCIPAL ELEMENTS OF THE SITING PROCESS

### 5.2.1 Criteria

The generalized criteria pursued by OWI by which to accept or reject a region, area, or site were developed along the lines originally proposed in GDEP (see Sect. 4.1.4). Whereas the GDEP criteria were quantitatively specific for salt [305 to 915 m (1000 to 3000 ft) in depth and minimum of 152 m (500 ft) in thickness], OWI criteria were broad enough to be applied to any rock. OWI defined the principal criteria of a suitable site as (1) hydrologic, tectonic, and mechanical stability; (2) type of mineralogy and petrology that allows the formation of an effective barrier against waste migration via the groundwater to the biosphere; and (3) sufficient areal extent, thickness, and in situ strength in which to construct a mined cavity for waste disposal (Lomenick, 1977; OWI, 1977).

Specific siting criteria [also called screening specifications (see below)] used during the OWI period are best illustrated by reference to the several locations where salt deposits were under consideration. Two widely applied criteria involved the depths to the top of any potential candidate salt unit (individual salt beds, salt cores in anticlines, or salt domes) and the thickness of the salt (individual salt beds and salt cores in anticlines). The latter criterion was relatively moot with regard to domes given their great vertical extent. Other criteria included avoidance of existing petroleum production and selection of trends where exploratory boreholes were at a minimum or the specific locations of existing boreholes were well known. Another criterion was avoidance of areas where conventional salt mining, solution mining of salt, and cavern storage

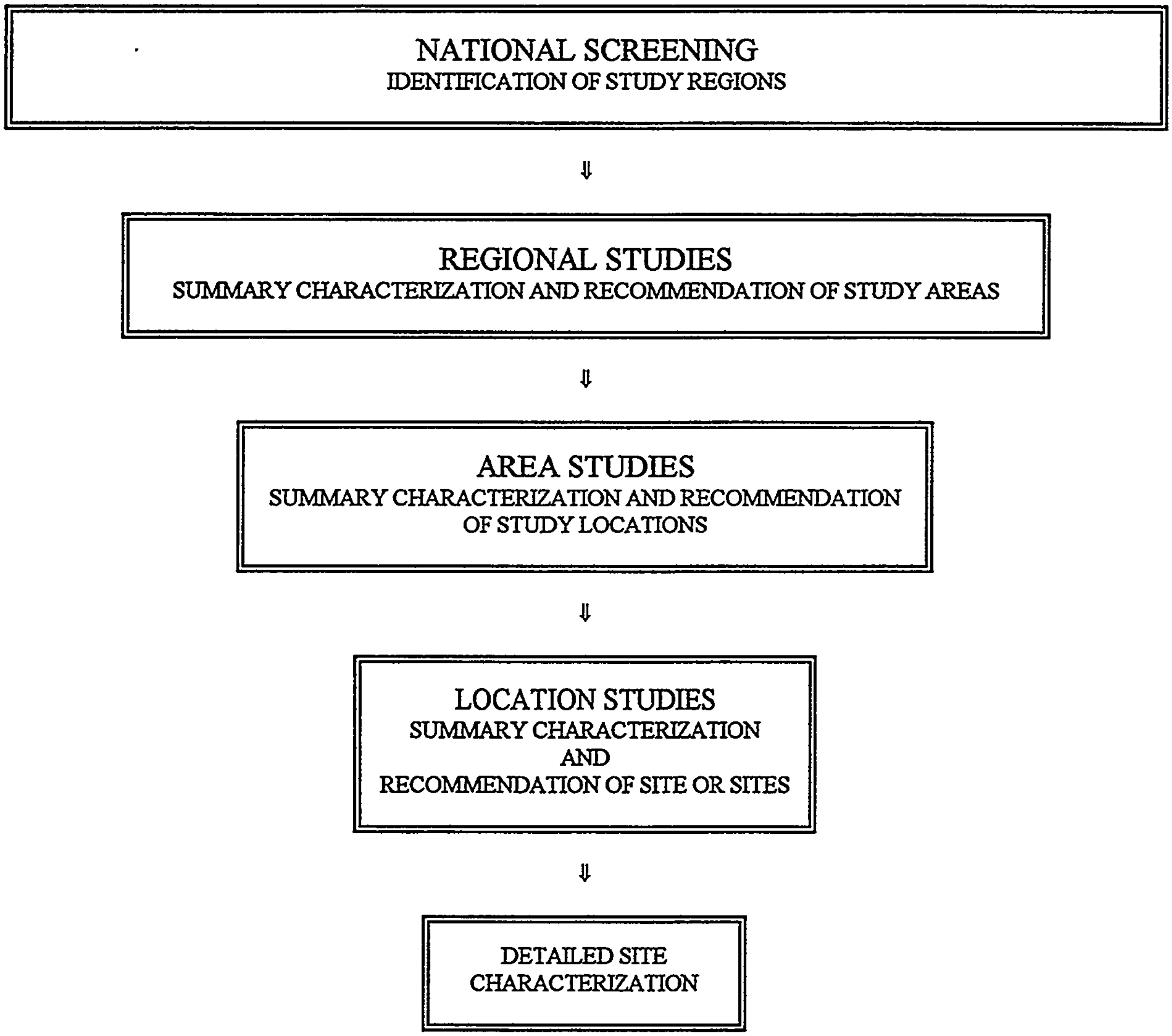


**Fig. 5.1 Phases of site identification and overview of the qualification process.**

projects were located. Other criteria considered the tectonic stability, hydrologic setting, rock mechanical properties, and socioeconomic issues beyond mineral resources (Brunton and McClain, 1977). Gradually, "criteria" came to refer to generic properties to which "specifications" could be added in a particular area or rock type if enough information were available for that area (Brunton et al., 1978*a*). Individual criteria were also developed for bedded vs domal salt deposits (Brunton et al., 1978*a*, 1978*b*). Consensus about rock stress, renewed or possibly ongoing uplift, and large-scale regional faulting were either unique or more applicable to salt domes. Likewise, downcutting by glacial erosion and the thickness of water-bearing glacial drift were applicable to areas only in the northeastern states (bedded salt).

In 1978, OWI published its set of criteria, which subsequently aided in the preparation of ONWI criteria and in the eventual DOE siting guidelines (10 CFR Part 960) (Brunton and McClain, 1977). The objective of the early investigations of Saline Group salts in the Michigan Basin was to identify locations at which the following criteria were met: (1) salt is at depths of 600 to 1000 m (1900 to 3200 ft); (2) the absence of petroleum-production and solution-mining (brining) operations; (3) a minimum number of boreholes that penetrate the salt section; (4) avoidance of areas that have poorly plugged boreholes or wells with ill-defined locations; (5) proximity to rail facilities; (6) isolation from population centers; and (7) favorable land ownership that minimizes competition from oil and gas leasing and numerous small-plot owners (Landes, 1976a).

In 1979 the DOE issued a four-volume NWTS "Criteria" document entitled NWTS Program Criteria for Mined Geologic Disposal of Nuclear Wastes (DOE, 1981). This document, which provided the framework for ONWI siting studies, discussed program objectives, functional requirements, and performance criteria in Vol. 1. Site-performance criteria to be used to screen sites and to evaluate the suitability of sites for the disposal of radioactive wastes were covered in the second volume, whereas the third volume reviewed repository performance criteria. Waste-package performance criteria were discussed in Vol. 4. The intent of this document was to specify criteria for a complete repository system, regardless of rock type, sufficient to ensure the isolation of the radioactive wastes with only minimal risk of their escape to the biosphere throughout the lifetime of the repository.

As stated, criteria were "purposefully general to allow for analysis of the interrelationships of the characteristics of specific alternative geographic locations" (DOE, 1981). The NWTS Site Performance Criteria addressed several aspects of the geologic environment such as site geometry, geohydrology, geochemistry, geologic characteristics, tectonic environment, and surface characteristics. As well, human intrusion, demography, environmental protection, and socioeconomic impacts were considered.

The intent of the 1979 criteria was to leave all options open while investigating general rock types in different areas. However, one of the major criticisms of such generalized criteria was the danger that such terms as *sufficient*, *acceptable*, and *adequate* are merely value judgments which could be reinterpreted at will to satisfy expediency rather than to address measurable differences in geologic environments.

**5.2.2 Disposal Concepts**

During the OWI-NWTS program, the disposal method under consideration was a deep-mined repository (see Fig. 5.2). It would occupy some 800 ha (2000 acres) within the subsurface and would accept canisters of solidified waste that had been derived from the composite liquid-waste streams involved in reprocessing. Any liquid HLWs were to be stored for a brief period (<5 years) in order to allow thermal decay prior to solidification. Solidified wastes, once placed into canisters, would also be stored, if so desired, up to 10 years prior to emplacement in a repository.

The basic design of a waste-management facility consisted of (1) a fuel-reprocessing plant that would convert liquid radioactive waste into dry solids (after separating the fission products) and place them into sealed containers or would repackage existing high-level solid wastes (i.e., spent fuel) and (2) a deep-mined repository (see Fig. 5.2).

At first, the repository was planned to be a disposal site for low-and intermediate-level wastes as well as for HLW, as shown in Fig. 5.2. Later, the low-and intermediate wastes were deleted from the repository concept. The earliest repository designs during the OWI program-management phase were for a hypothetical and unspecified "generic" geologic formation and were based on two assumptions (1) all investigative and experimental phases would produce positive results at each step and (2) engineering design would overcome any deficiencies in the waste package or any problems caused by waste-rock reactions. Under these assumptions, two management options were considered, namely retrievable storage and permanent disposal. Both concepts were developed simultaneously because the expectation was that some of the multiple repositories eventually constructed would initially use the option of retrievability.

However, President Carter's ban on reprocessing placed a greater emphasis than before on retrievability. Because spent fuel assemblies would now become the waste form, interim storage prior to final disposal became a viable dual concept. Coincident with the ban and because of policy changes and other factors, fewer repositories than the six envisioned in the expanded ERDA/NWTS would be needed.

Mined geologic disposal constituted the only method under consideration by ONWI following the recommendations of the 1979 IRG report and President Carter's emphasis on "technical conservatism" (Carter, J.E., 1980). The acceptance of mined geologic disposal as the most suitable near-term option was further supported by the EIS and DOE's statement on waste confidence rulemaking (DOE, 1980) in which DOE presented the basis for its position that safe disposal of radioactive HLW in geologic repositories would be available when needed (see Appendix C). In early 1980, President Carter added continued support for this approach in his message to Congress. On the basis of these developments, the selection of the mined geologic disposal option (mined repositories) was formally published in the *Federal Register* in mid-1981 (*Federal Register*, 1981).

It is worth noting that the need for conservatism in the design of facilities for the permanent storage of radioactive wastes had been consistently recognized and pursued in U.S. nuclear waste management programs from their very earliest days. Conservatism provides adequate margin to cover unanticipated contingencies and uncertainties in the criteria, analyses, or design of the NWTS repositories.

In the 1950s, the Committee on Radioactive Waste Management of the National Research Council recognized that conservatism in the design of deep geologic storage facilities would be necessary to overcome the uncertainties inherent in any such long-term activity as permanent waste storage. Conservatism became an even more important element in nuclear waste management programs when stressed in the IRG report to the President. The IRG recommended that nuclear waste disposal should proceed on a step-wise basis in a technically conservative manner.

ONWI's approach further emphasized a "multibarrier approach to containment and isolation, the requirement for retrievability, and the extensive use of peer reviews in the conduct of the program." "Multibarrier" referred to (1) engineered barriers such as waste form, waste package, and backfill; and (2) natural barriers provided by features such as rock type and composition, structure and hydrology. The technical approach included the conceptual design of a repository in each of three rock types (i.e., bedded salt, domal salt, and basalt). The initial design started with certain assumptions as to depth of the formation, the mining

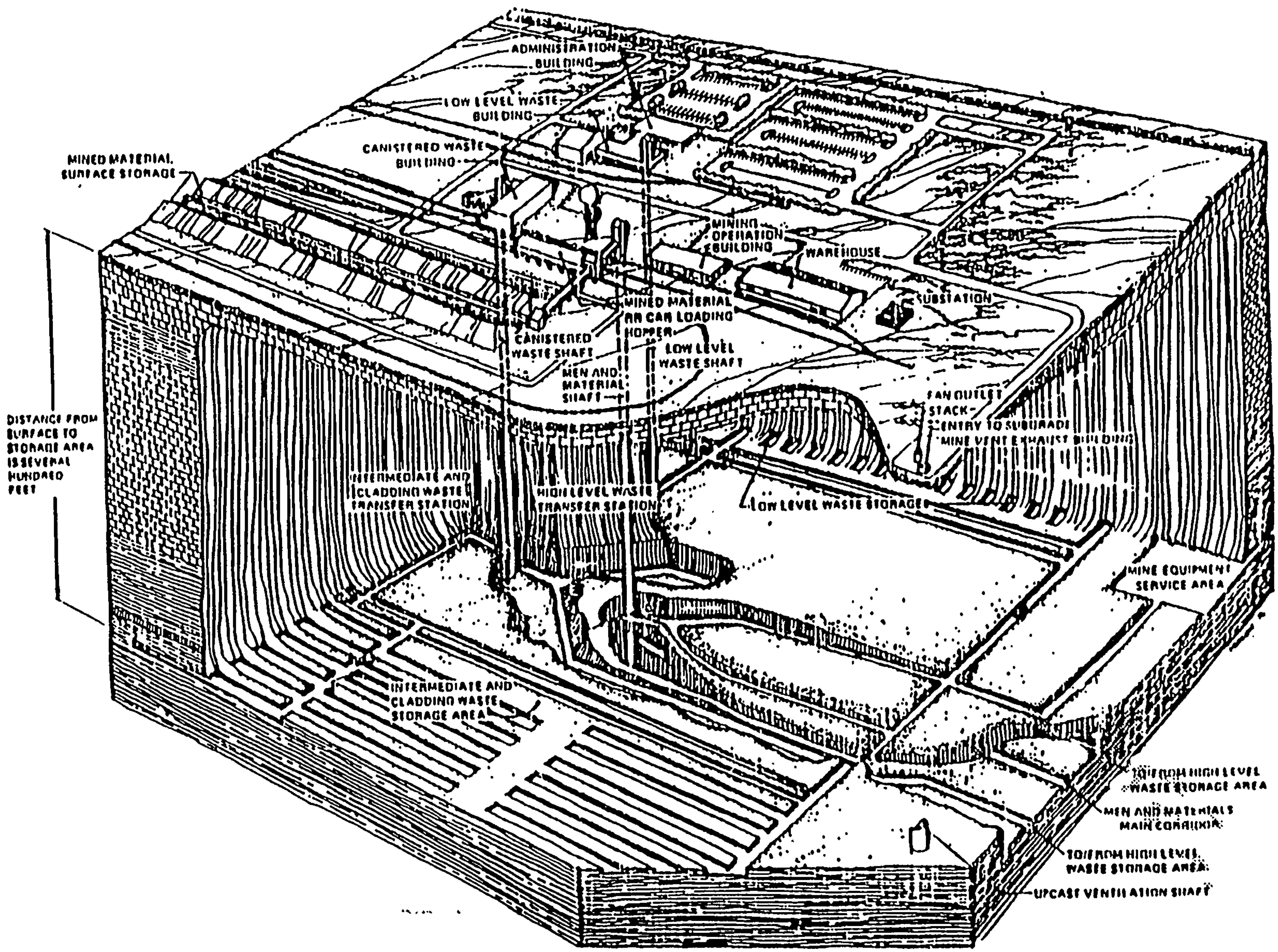


Fig. 5.2 A schematic of the proposed waste isolation facility as envisaged in the NWTS program.

techniques to be used, the configuration of the above-ground and below-ground facilities, the waste-package design, and the total waste-handling facilities. Independent of geologic siting studies, work on the engineering design of a repository relied on the general range of data for each rock type to develop a model design that could later be tailored to a selected specific site. The purpose of the design studies was primarily to identify at a very early stage of investigation the gaps in needed geotechnical data for repository construction.

**5.2.3 Relationships with States, Indian Tribes, and the Public**

From the beginning, OWI had a public affairs program to inform state agencies of its actions in respective states and to provide public notices of investigations. It was believed that a public consensus could be obtained by providing information to the states and allowing them to review the investigation and documentation of the siting process. State agencies were informed at an early date of any work planned within their respective state, and technical meetings were also held to inform state officials (Zerby et al., 1976; Zerby, 1977*a*, 1977*b*; OWI, 1976*a* 1976*b*; Kaplan, 1977).

In addition, OWI frequently contracted with state research agencies for technical investigations. For example, the University of Texas Bureau of Economic Geology and LSU Institute for Environmental Studies conducted the investigations which led to stratigraphic test holes in bedded-salt formations and salt domes, respectively.

Nevertheless, several adverse political situations developed during the OWI period, all of which were connected with stratigraphic test drilling. By early 1977, OWI investigations in Michigan had proceeded to the point in which stratigraphic test holes to obtain core samples were being planned. The public announcement of the OWI's plan to explore for a "nuclear waste test site" resulted in so vehement a public protest in Michigan that all work there was ultimately discontinued by ERDA.

As had happened previously in Michigan, public announcements in both Texas and Louisiana in 1978 of test drilling brought immediate public protest. The initiation of a deep drilling program at Vacherie salt dome in northern Louisiana brought a confrontation with local public-interest groups who prevailed on the state oil and gas agency to revoke the drilling permit. The Louisiana legislature passed a law that prohibited radioactive-waste repositories and drilling to investigate sites for such repositories. Subsequent hearings occurred during which personnel from both OWI and the Institute for Environmental Studies at LSU provided information on the scope and nature of investigations leading to the selection of a test-hole site. LSU's liaison role proved to be a deciding factor in averting a major political confrontation. After the hearing, the drilling of a hole at Vacherie Dome and of a second hole at Rayburns' Dome proceeded uneventfully. When OWI announced intentions to drill test holes in Randall and Swisher counties, Texas, they were greeted with another local public protest. The University of Texas Bureau of Economic Geology (TBEG) had selected the drill site, and its role in the investigation contributed to the swift resolution of that confrontation.

These localized situations were in addition to national-level controversies over the extensive scope of the ERDA/NWTS, the large number of states in which investigations were planned, and related political opposition. Thus, both OWI and ERDA, as the major organizations active in the NWTS, were confronted with problems in the area of political and public interfacing.

The official policy of DOE with respect to state interactions was known as the "consultation and concurrence" approach, as described by the IRG in 1979 (IRG, 1979) and by a directive from President Carter (Carter, J. E., 1980). This approach provided for state and local representation in the site-selection process. ONWI recognized sociopolitical considerations as a major element in any siting activity and consequently established "affirmative interaction" with state via official groups, such as the National Governors' Association and state planning agencies.

At the time of the transition from OWI to ONWI, field activities were in progress in Texas, Louisiana, and Utah. In each state, a major political hurdle—drilling the first stratigraphic test hole—had been overcome, partly by the activities of state agencies that were active in the investigations.

In Texas, the TBEG provided liaison between the NWTS and the Governor's office both for salt-dome and bedded-salt investigations during the earlier stages of work. Later, the Texas Energy and Natural Resource Advisory Council became the official contact with the Governor's office, while TBEG continued under contract to conduct geologic investigations (Battelle, 1980).

In Louisiana, DOE and the state agreed to principles of understanding, which provided for test drilling to proceed along with discussions with state officials. During the early stages, the LSU Institute for Environmental Studies served as a liaison with the Governor's office, but in 1980 the legislature established a joint House and Senate Natural Resources Committee with a designated state representative for interaction with DOE (Battelle, 1981*a*). Within that framework, working relationships between DOE and state and parish representatives were maintained by periodic briefings.

In Utah, DOE organized periodic public meetings and briefings in the state on siting investigations with the coordination of the Utah Nuclear Waste Repository Task Force that was appointed by the Governor. The "working partnership" concept led to DOE's providing grants to the state to fund the establishment of a state agency, whose purpose was to develop state policy and perform independent technical and socioeconomic reviews of DOE's waste investigations (Battelle, 1981*a*).

The NWTS investigations of Mississippi salt domes involved the interaction of DOE and ONWI with the State Energy and Transportation Board, which was given authority by the Governor to develop, coordinate, and review all nuclear-related activities in the state. DOE and ONWI participated in public meetings and briefings for legislators and for the media. As they had in other states (i.e., Utah, Louisiana, and New Mexico) DOE provided grant funds for Mississippi to independently develop its review agency (Battelle, 1981*a*).

Before studies began in earnest on crystalline rocks, ONWI had begun a series of briefings for officials and legislators in those states where work was to be conducted. Several such states established independent groups to serve as their official representatives to monitor these waste investigations; others appointed existing state agencies such as geological surveys or environmental-protection divisions to provide the necessary liaison (Battelle, 1981*a*).

In early 1982 President Carter responded to a recommendation from the IRG by creating the State Planning Council by means of Executive Order 12192. Its charge was to provide state perspectives and advice to the Executive Branch and to work with the Congress in making and implementing decisions on waste management and disposal. Additionally, DOE began using the ten regional offices assimilated from the Federal Energy Regulatory Commission at the time DOE was created . These offices represented the Secretary of Energy by serving as a mechanism to interface with states, localities, and the public. They also provided information to the public; collected information relevant to public opinion on DOE policy, program, and implementation; and helped to organize meetings with state and local officials and the general public.

**5.2.4 Technical Issues**

In October 1978, a working group was established by DOE and the USGS to prepare a technical plan designed to guide earth-science research directed at resolving earth-science issues connected with the development of mined repositories for disposal of radioactive waste. The working group and its five subgroups consisted of 56 people. That plan, the Earth Science Technical Plan, became a part of the National Plan (DOE, 1982), which was called for by President Carter on February 12, 1980. The plan described the earth-science R&D that must be done to establish a safe, mined, geologic repository. To that end, the report discusses technical questions, shows how current research tasks relate to those questions, recommends where program emphasis should be placed, identifies technical questions requiring additional effort, and classifies and describes the various earth-science research tasks performed by DOE and USGS. It describes the progress of the program and provides estimates of the time and cost required to resolve the remaining technical questions operating stage.

Another component to the National Plan was the *Status of Technology for Isolating High-Level Radioactive Wastes in Geologic Repositories* (Klingsberg and Duguid, 1980). It presents a "then" current and expanded status report on the technology of geologic disposal of HLW and spent fuel. In addition to being part of the National Plan, this report was also intended to be useful to managers of government technical programs, members of Congress, interested members of the public, and students of nuclear engineering and the earth sciences.

One of the decisions made in response to the report on status of technology (Klingsberg and Duguid. 1980) was to pursue crystalline rocks rather than shale as potential host rocks for a second repository. The principal reason for this deferral of shale was the report's conclusion that "although no rock was a first choice on strictly technical grounds," the suitability of shale could not be determined except on a costly and time-consuming site-specific basis because of the complexity and variability of shales (Klingsberg and Duguid, 1980). Subsequently, ONWI recommended that the R&D required for a repository in shale be deferred to some future date (Battelle, 1981*b*).

A technical issue common to all investigations was the need to develop means for determining the tectonic and hydrologic stability of the rock formation under consideration. Research programs were developed to gain understanding of critical geological phenomena, such as (1) movement of fluids in largely impermeable rock (2) geochemistry of waste-rock interactions (3) mineral and rock stability under ambient and waste-emplacement environments and (4) processes that affect radionuclide migration.

Using the leading candidate rock type as an example, the principal technical issues confronting rock salt at that time included (1) rock mechanical stability and salt creep; (2) brine migration; (3) salt dissolution, including breccia pipes, and for domes, that associated with caprock development; (4) disposal of the excess salt excavated during repository construction; (5) methods and materials by which to plug and seal old or abandoned boreholes; and (6) interactions between waste and waste containers and the corrosive salt-brine environment.

Other technical issues included rock mechanics and, related to mine construction, analysis of disruptive events, and safety assessment. These topics also embraced the generation of computer codes and the design of testing methods by which thermal, mechanical, and hydraulic properties could be better measured. Especially important in the latter area were procedures and instrumentation for in situ testing.

Additional technical issues having design implications included (1) waste-solidification methods; (2) waste forms; (3) canister materials and types; and (4) canister-emplacement equipment and different methods of emplacement.

In October 1980, DOE issued its Environmental Impact Statement, *Management of Commercially Generated Radioactive Waste* (DOE, 1980*b*). Included within this multivolume report was a comprehensive statement of technical issues affecting the process from siting through construction and operation of a repository. DOE also initiated a new approach to site selection, in which the factors important to the selection of a waste-repository site were examined in detail and compared with relevant technical criteria in order to demonstrate the technical adequacy of the site. This new approach became more firmly developed in the siting process in response to the need to quantify the large amount of data collected in siting investigations. It also became necessary in order to satisfy QA requirements and to document the impartial nature of the selection process.

The repository-design studies using data derived from the siting investigations created the need for additional geotechnical parameters. For instance, in studying salt domes, it was found that the internal salt temperature was higher than had been assumed in prior repository-design studies. Apparently, the deep-rooted salt stem served as a heat conduit for deep in the crust to shallower levels because of the high thermal conductivity of salt as compared to other rocks. As data on the geometry of several domes became available, it was possible to develop (1) a realistic analysis of the construction cost in one dome vs another and (2) overall technical feasibility of constructing and operating a repository in each. Repository-design studies pointed to the need to develop equipment for drilling, emplacing, retrieving, and monitoring waste canisters and for closing the repository. Such equipment would have to be suitable for the various rock types under consideration.

Studies of repository and waste-package design brought to light a number of factors, conditions, and processes which led to the need for additional development. They included (1) the optimum waste form that would provide long-term containment of radionuclides; (2) canisters to contain the waste; (3) appropriate spatial density of containers that would be optimal, both for retrievable storage and permanent disposal in the various rock types; (4) appropriate kind and configuration of backfill materials; (5) the methodology for the assessment of long-term safety and the instrumentation for long-term monitoring. The waste package envisioned would provide multiple layers, each of which would act as a barrier to the movement of radionuclides from the repository. The final engineered barrier would be the sealing of the repository, all shafts, and any nearby boreholes with appropriate material to ensure waste isolation. The selected host rock and its geohydrologic environment would form a natural barrier.

**5.2.5 Participating Organizations**

In the early stages of OWI, work was contracted to individual consultants, state agencies, and the USGS. However, in 1977, the management system was changed. The breadth of investigations had become too large for in-house management of each task, and problems arose from the start-stop aspect of contracting each task individually. In order to resolve these problems, OWI initiated the concept of the Geologic Project Manager (GPM). The function of a GPM firm was to provide (1) all technical services needed for each stage of siting investigations and (2) the comprehensive record-keeping and QA for the data that would be the basis of decision making at the time repository sites were eventually selected. A GPM was free to perform the work itself or to subcontract work to other firms, consultants, or agencies.

Plans for and results of site and rock investigations were examined by a peer review group called the Geologic Review Group (GRG) (OWI, 1976*b*). The GRG was composed of six distinguished members (four geoscientists, one physicist, and one engineer) in technical areas critical to waste-siting studies. It was asked to "(1) study and critically review the long-term geologic stability of rock units considered for geologic disposal of nuclear waste and (2) to study and critically review all geologic study plans and activities of the NWTS leading to site selection and development of facilities that will safely dispose of commercial radioactive waste that must be delivered to federal repositories for terminal storage." The GRG reviewed essentially all aspects of the waste program being carried out under OWI, including the criteria documents that were developed at the time.

During this period, the NWTS had in essence been an integrated geologic siting program that involved several rock types and several sites under consideration both on private lands and on federal (DOE) reservations (NTS and Hanford Site).

As ONWI assumed technical management of the redefined NWTS (see Sec. 5.1), the basalt project at the Hanford Site had become known as the BWIP and was the technical responsibility of the Rockwell Hanford Company. This project was administered by the Richland Operations Office of DOE in Washington. Likewise, the studies being conducted at NTS had been renamed the NNWSI and were administered by the Nevada Operations Office (NVO) which was located in Las Vegas. Technical work within this project continued to be undertaken by the USGS and several national laboratories, namely, Lawrence Livermore National Laboratory (LLNL), Lawrence Berkeley National Laboratory (LBNL), Los Alamos Scientific Laboratory (LASL) [now Los Alamos National Laboratory (LANL)], and SNL.

The remainder of the NWTS centered on those lands and sites not directly under the control of DOE. The redefined NWTS undertaken by ONWI initially focused on sites where rock salt was the potential host rock. Crystalline and argillaceous rocks eventually were added to the NWTS/ONWI program. DOE administration for ONWI program was initially directed through the Richmond Operations Office, Washington. A DOE program office was established shortly thereafter in Columbus, Ohio.

In his January 1978 Presidential message to Congress, President Carter outlined a comprehensive program for the management of radioactive wastes. At that time, he established the State Planning Council (DOE, 1978), whose purpose was to advise him and the Secretary of Energy on means to strengthen the relationships among all governmental units participating in activities regarding radioactive waste disposal. Membership on the council consisted of governors, state legislators, various local governmental officials, a representative of an Indian nation, and upper-level representatives of several federal agencies. This group's principal task was to recommend measures by which there could be improved federal-state communication and cooperation within the waste management program. The State Working Group was also created in 1980. It consisted of representatives from all those states in which DOE was conducting site-selection studies (Battelle, 1980). Funds were supplied by DOE to the National Governor's Association to support this group, but both groups shared information on the various active projects and reviewed related reports.

The peer review process, initiated under the GDEP and continued under the OWI, was considerably expanded by Battelle when the program was transferred from OWI to ONWI. A program-wide Technical Review Committee was established in addition to separate review groups in engineering (Engineering Review Group) and in the geosciences GRG. In late 1979, another group, the Program Review Committee, was formed to provide the nontechnical public with the opportunity to review the program within the context of both present and future nuclear-waste issues and policies. This committee was established as a review committee rather than an advisory group in order to provide an objective and independent judgment of the program. It brought an interdisciplinary perspective to a technological program that had a variety of nontechnical implications and issues. These four review committees/groups continued to function for several years.

Additionally, both the BWIP and NNWSI projects had separate independent review committees which were established in the late 1970s. Some of the technical reviewers for ONWI review groups also served in a review capacity for one or both of these other projects and were deliberately selected by ONWI to provide some interface between the projects. The review committee for the BWIP met on an annual basis for a few years and was then disbanded. The approach of the NNWSI was to obtain a group of appropriate individuals to review some particular aspect of the program when there seemed to be a need. Thus, the composition of that review group varied from time to time in response to the technical topic under review.

# 6. PERIOD: 1983–1987

The mid-1980s saw a profusion of important developments in the waste-disposal program. The siting process was sharply focused as a result of such things as establishment of NRC criteria, maturation of understanding of technical issues, and passage of the NWPA. This period (1983-1987) brings the approximately 30 years of siting efforts up to a significant point-the designation of a single site that is to undergo detailed characterization studies under a highly sophisticated evaluation process which included performance assessment. The developments and decisions made during this five-year period further advanced the waste-disposal program and the developments at its single site at YM. Future efforts are to focus on such areas as site testing, resolution of outstanding key issues, assessment, and license application.

As new activities were phased in, some ongoing activities and programs were phased out. In the following discussion, these partly overlapping activities are addressed in order of chronology rather than of perceived importance.

## 6.1 THE PROGRAM FOR A SECOND REPOSITORY

Although DOE had earlier initiated national surveys of argillaceous rocks, crystalline rocks, and geohydrologic environments regardless of rock types, only the study of crystalline rocks was carried forward into this mid-1980s. Because of the complexity and wide range of properties and behavior of shale, it was concluded (see Sect. 5.2.4) that the suitability of shale could be determined only on a site-specific basis that would be very costly and time consuming (Klingsberg and Duguid, 1980; Battelle, 1981*c*).

The study which was based on environmental and other conditions, became stalled because of disagreements and lack of response (Appendix E). Therefore, crystalline rocks were selected as the chief contender as the host rock for a second repository. However, in 1984, a new initiative was started for sedimentary rocks.

### 6.1.1 Crystalline Rock Project

A national survey of crystalline rocks was made in 1983 by the Office of Crystalline Repository Development (OCRD), (OCRD, 1983). It concluded with a recommendation that crystalline rocks in three regions be studied first because of the likelihood that those regions could be explored more effectively and that suitable sites probably could be found, characterized, verified, and licensed more readily than those in other regions. Those three recommended regions are the northeastern, north central and southeastern regions; they include parts of 17 states (OCRD, 1983; see Fig. 6.1 and Appendix. V).

With the establishment of the Crystalline Repository Project in 1982, Battelle's Office of Crystalline Repository Development established a review function similar to the one ONWI had established in 1978, with a project-wide Technical Review Committee and separate review groups in the engineering, geosciences, systems, regulatory, and environmental/institutional areas. Those who chaired the separate groups collectively made up a project-wide review committee.

#### 6.1.1.1 Geologic characterization of crystalline rock regions.

Draft regional characterization reports were issued in May 1983 by DOE's Crystalline Repository Project Office for review by the affected states. These reports contained information taken only from public literature on the geologic, environmental, and socioeconomic conditions of each region. The reports were intended to be issued in final form immediately after review by the state. Instead it developed and issued a screening methodology document (Battelle, 1985) to describe how the region-to-area screening would be conducted and then reissued the regional characterization reports in a revised draft for further state review and comment (DOE, 1986*b*). The draft regional characterization reports were reissued in December 1984; the final report was issued in August 1985.

#### 6.1.1.2 Recommendation of 12 potentially acceptable sites in crystalline rocks.

DOE issued a draft *Area Recommendation Report* (ARR) in January 1986 that identified 12 potentially acceptable sites for crystalline rocks in 7 states: Georgia, Maine, Minnesota, New Hampshire, North Carolina, Virginia, and Wisconsin. The draft report also identified an additional eight potentially acceptable areas located in Georgia, Minnesota, Virginia, and Wisconsin (DOE, 1986*b*). No areas were proposed in 10 of the original 17 states identified in the national survey.

A 90-d public comment period was held on the draft ARR. DOE made funds available to the 17 potentially affected states and 28 Indian tribes to enable them to review the document. Additionally, DOE offered to hold public briefings and public hearings on this document, even though there was no statutory requirement to do so on such a preliminary report. Nearly 80 public briefings and hearing were held during the review period in 15 of the 17 states (Pennsylvania and Maryland did not request briefings or hearings). More than 60,000 comments on the ARR were received as of June 30, 1988, which was the congressionally mandated (NWPA) phase-out date of the Crystalline Repository Program.

### 6.1.2 Sedimentary Rock Project

To increase the diversity of rock types under consideration by the geologic repository program, DOE initiated in 1984 a project which had as its objective the evaluation of the common types of sedimentary rocks (other than salt) to determine the likelihood of their being suitable as hosts for a repository. The study was conducted by ORNL. A draft report of that study concluded that shales ranked highest, followed in decreasing order of likely suitability by sandstone, carbonate rocks and anhydrock, and chalk, but that suitable sites probably could be found in each rock type. Extensive technical reviews determined that the method used to score and rank these rocks had significant defects and that shale and sandstone probably would rank equally as high if the evaluation were to be done again after defects in the methodology were corrected. However, by that time (1988), a second repository had been deferred, and DOE terminated the revision of the draft report.

## 6.2 NATIONAL SITING PLAN

The *National Plan for Siting High-Level Radioactive Waste Repositories* was published in draft form by DOE in February 1982 and in final form in March 1983 (DOE, 1982). The Plan outlined the siting process and the program that was organized to implement the process. It presented a description of the activities that had been undertaken and those that were planned to screen successively smaller portions of land within the United States in order to identify suitable candidate sites, one or more of which would be selected as a permanent waste repository.

The Plan described criteria that could be used in assessing site suitability and outlined the principles that DOE would use in the process for identifying candidate sites and the selection of one or more for licensing. According to the Plan, national and regional surveys were to be conducted on lands other than DOE-controlled reservations (hereafter called non-DOE lands) and would consist of a review of existing data obtained through literature searches. Because DOE lands are of smaller size than those of a region, the surveys of those smaller DOE areas were to be started at the same stage as the area surveys of non-DOE lands. The surveys of successively smaller tracts (areas, locations, and sites of Fig. 6.1) within regions or at DOE reservations were to include geologic and environmental field studies such as shallow and deep drilling, geophysical surveys, environmental surveys and field-confirmation activities.

At the time the Plan was written, the criteria to be used to determine site suitability were still being developed. Because the EPA standard for disposal of high-level radioactive waste and the NRC's technical criteria were only in draft stages undergoing technical and public review and had not been finalized, DOE developed its own set of interim criteria. These interim criteria were selected in light of the draft NRC criteria and were thought to be sufficiently comprehensive to support early siting decisions, although this Plan was superseded by the NWPA (NWPA, 1983). The purpose of NWPA was to provide for the development of repositories for the disposal of HLW and spent nuclear fuel, to establish a program of research, development, and demonstration regarding the disposal of HLW and spent nuclear fuel, and for other purposes (NWPA, 1983). The NWPA provided DOE with a definite schedule and sequence of steps that must be followed for siting, licensing, and operating the first geologic repository and for the siting of a second geologic repository. The schedule called for the operation of a safe and environmentally sound, licensed geologic repository by 1998. Section 112 of the NWPA gives DOE the responsibility for conducting the siting process. Before the NWPA was passed, DOE was involved in the siting process under authority established by AEC in 1954, the Energy Reorganization Act of 1974, and authorization and appropriation bills passed by Congress from 1975 through 1983.

The NWPA included provisions to ensure participation by affected states and Indian tribes and by the public in the decision-making process for nuclear waste disposal, integrated the roles of multiple federal agencies that were involved with the implementation of the nuclear waste program before passage of the NWPA (see Appendixes J and K), and established a Nuclear Waste Trust Fund, which was to be financed by a per-kilowatt charge to electric utilities that operate nuclear plants.

A summary of the siting procedure stipulated by the NWPA follows:

1. Within 90-d of the date of enactment, the Secretary must identify the states determined to have one or more potentially acceptable repository sites.

2. Within 90-d of such identification (I) the Secretary must notify the governor, state legislature, and the tribal council of any affected Indian tribes in each identified state of the potentially acceptable site or sites.

3. Within 180-d of the date of the enactment and with the concurrence of the NRC, the Secretary must issue general guidelines for the recommendation of repository sites [NWPA, Sect. 112 (A)]. The Secretary must use those guidelines in considering his recommendation of candidate sites. Before guidelines are issued, the Secretary is required to consult with the Council on Environmental Quality, the administrator of EPA, the Director of the USGS, and interested state governors. The NWPA further requires that the guidelines specify certain technical considerations and that the Secretary consider such things as cost, impact of transportation, and various geologic media that could be potentially suitable for a geologic repository. (NWPA Sect. 6.4). The NWPA requires the Secretary to use these guidelines in considering candidate sites for recommendation.

4. The Secretary must nominate at least five sites that they determine suitable for site characterization, but only after consulting with the governors of affected states or the governing body of affected Indian tribes. Each site nomination must be accompanied by an Environmental Assessment (EA), which includes a detailed statement of the basis for each recommendation, the probable impacts of the site characterization activities planned for each site, and a discussion of alternative activities relating to site characterization activities planned for each site, and a discussion of alternative activities relating to site characterization that may be undertaken to avoid such impacts. Before the EA can be issued

and before the sites are nominated, the Secretary is to hold public hearings in the vicinity of each site to inform the residents of the proposed nomination and to receive their comments. The Secretary shall solicit and receive any recommendations of the residents with respect to issues that should be addressed in the EA and the subsequent DOE Site Characterization Plan (SCP).

5. The Secretary must recommend three of the nominated sites for characterization as candidate sites. To select the three sites, the Secretary may use only available geophysical, geologic, geochemical, and hydrologic data, and other available information, without conducting any preliminary borings or excavations. This process is to be repeated later for the second repository on a different schedule.

6. The President is to review the three candidate sites recommended by the Secretary. The President may approve or disapprove the recommendations, permit the characterizations to proceed by taking no action for 60-d, or delay the decision for 6 months if he feels that insufficient information is available.

7. The Secretary must recommend one site for development as a repository. This site must have been characterized according to Sect. 113 of NWPA, which requires the Secretary to submit a SCP for review and comment to (1) the NRC, (2) the state in which the site is located, and (3) the governing body of any affected Indian tribe. In addition, the SCP must be made available for public review and comment. The SCP must describe a wide range of activities by which the Secretary will be able to collect detailed information about the site, including the construction of exploratory shafts for tests at repository depth. However, before the exploratory shaft can be sunk, the Secretary must hold a public hearing in the vicinity of the site to explain the SCP to the local residents and to receive their comments. After site characterization has been completed, public hearings must again be held to inform the residents in the vicinity that the site is being considered for development as a repository. The Secretary's recommendation to the President of the first site to be developed as a repository must be accompanied by an EIS as required by Sect. 114 of the NWPA.

   The final step of the siting process calls for the President to recommend the first repository site to Congress by March 31, 1987. The NWPA provides for an extension of this date by as much as one year.

8. Within 60 of the recommendation by the President of a site for development as a repository, the affected state or Indian tribe may submit a "Notice of Disapproval" to Congress. Unless Congress passes a joint resolution approving the site recommendation, the site may not be used as a repository. If the "Notice of Disapproval" is not overridden, the President is required to recommend another site within 12 months.

9. The Secretary must apply to the NRC for an authorization to construct the repository.

## 6.3 DOE SITING GUIDELINES

General guidelines for recommendation of sites for nuclear waste repositories were developed in accordance with the requirements of NWPA (DOE, 1983*b*). Draft siting guidelines were released to the public in February 1983. Following public review and extensive consultation with the states, the guidelines were forwarded to the NRC for its concurrence on November 22, 1983. The guidelines were then revised to accommodate NRC's comments, and in May 1984, the revised guidelines were forwarded to the NRC for its final concurrence, which was given. The final siting guidelines were published in the *Federal Register* as 10 CFR Part 960, December 6, 1984 (DOE, 1985*a*). DOE siting guidelines are designed to (1) establish performance objectives for a geologic repository; (2) define the basic technical requirements that candidate sites meet; (3) detail how DOE's OCRWM will implement its site-selection process; (4) specify the geologic considerations that are the primary criteria for site selection, including the elements that would qualify or disqualify a site; and (5) consider factors such as proximity to population centers and natural resources, the cost and impact of transportation, and the advantages of regional distribution of repositories.

The NWPA specifically states that the guidelines must:

1. Specify detailed geologic considerations that shall be primary criteria for the selection of sites.

2. Specify factors that qualify or disqualify any site from development as a repository.

3. Take into consideration (a) the proximity to sites where HLW and spent nuclear fuel are generated or temporarily stored and (b) the transportation and safety factors involved in moving such waste to a repository.

4. Require the Secretary to consider the cost and impact of transporting to the repository site the solidified HLW and spent fuel.

5. Require the Secretary to consider the various geologic media in which sites for repositories may be located and, to the greatest extent practicable, to recommend sites in different rock types.

The guidelines are divided into two parts: (1) a postclosure part, the period after the repository is permanently sealed and (2) a preclosure part, the period of repository siting, construction, operations, closure, and decommissioning. Both parts include technical and system guidelines. The technical guidelines pertain to the specific characteristics of the site that are considered to have a bearing on postclosure and preclosure performance of the repository. The system guidelines pertain to the expected performance of the total system, including its engineered components. The system guidelines are designed to protect public health and safety and preserve the quality of the environment. Nineteen technical guidelines, four system guidelines, and three implementation guidelines were established, all of which must be considered and evaluated in the siting process. The technical guidelines contain qualifying, disqualifying, favorable, and potentially adverse conditions that must be considered when the potential of a site is evaluated. Further, under the guidelines, three siting provisions are stipulated that concern the diversity of geohydrologic settings, "diversity of rock types," and, for purposes of a second and subsequent repositories, regionality.

## 6.4 DOE MISSION PLAN

The NWPA required the Secretary to prepare a Mission Plan for DOE, " which shall provide an informational basis sufficient to permit informed decision to be made in carrying out the repository program and the research, development, and demonstration programs required under this Act." A draft *Mission Plan* was to be issued no later than 15 months after enactment of the Act. DOE issued a draft overview in December, 1983, and published the complete Mission Plan in July, 1985 (DOE, 1985*b*).

## 6.5 IDENTIFICATION OF NINE POTENTIALLY ACCEPTABLE SITES

In compliance with the NWPA, in February 1983, DOE identified nine potentially acceptable sites for the first repository in the following locations (1) Vacherie Dome, Louisiana (salt dome); (2) Cypress Creek Dome, Mississippi (salt dome); (3) Richton Dome, Mississippi (salt dome); (4) YM (tuff); (5) Deaf Smith

County, Texas (bedded salt); (7) David Canyon, Utah (bedded salt); (8) Lavender Canyon, Utah (bedded salt); and (9) Reference Repository Location (RRL) at the Hanford Site, Washington (basalt flows).

The locations of these potentially acceptable sites are shown in Fig. 6.1. With the exception of Cypress Creek Dome, which underlies national forest lands, the salt sites are on private lands. The two nonsalt sites are on lands under the control of the federal government. All of the Hanford Site is on DOE dedicated lands. Some of YM is on DOE's NTS, and some of it lies on lands under the jurisdiction of the U.S. Departments of Defense (Air Force) and Interior (Bureau of Land Management). For YM and Hanford, siting was based on the concept of prior land use involving DOE facilities. DOE's reasons for selecting these nine sites are summarized in Appendix F. At the time the NWPA was enacted DOE's siting program had progressed to the site-survey phase (See Fig. 6.1) for seven of the sites and to the location-survey phase for two (Swisher and Deaf Smith Counties, Texas). Because the areal extent of these DOE lands was small in comparison with a province or region, the screening of these tracts began at the area phase of the overall site-selection process. By contrast, screening conducted on lands that were not included under the DOE prior-use concept began with a national survey for each potential host rock (Sect. 6.1.2).

The identification of the nine potential sites was based on the data collected during several years of geologic and environmental studies and on existing siting criteria. The site-screening decisions were based on technical factors that evolved throughout the screening period and as specified in a number of published documents.

## 6.6 ENVIRONMENTAL ASSESSMENTS (EAs)

The NWPA required the Secretary to nominate at least five sites as suitable for site characterization and to recommend three of the nominated sites to the President for characterization as candidate sites for the first repository. The NWPA further required that each nomination of a site be accompanied by an EA that includes a detailed statement of the basis for making that nomination.

On December 20, 1984, DOE issued draft EAs for each of the nine sites identified in February 1983 as a "potentially acceptable site" for a first geologic repository (DOE, 1984*a-j*). DOE decided to publish the EAs in draft form for review and comment, which caused a postponement of the January 1, 1985, date required by the NWPA for site nomination and recommendation.

Following issuance of the draft EAs, public hearings were held in each of the affected states in order to receive comments from local citizens. As a result, nearly 20,000 written comments were received. These comments were organized by subject and were either accepted as improvements to the EAs or a response was drafted explaining the reason for not accepting them. These responses were published in Vol. 3 of the EA (DOE, 1986*d-h*).

As the (final) EAs were being prepared, DOE requested the NAS and NRC Board of Radioactive Waste Management to conduct an independent review of the ranking methodology used to evaluate sites for recommendation for characterization. Whereas this Board found the methodology appropriate, it also suggested areas in which the evaluation methodology could be strengthened (NAS and NRC, 1985). Consequently, plans were made with the Board for additional coordination and review during late 1985 and

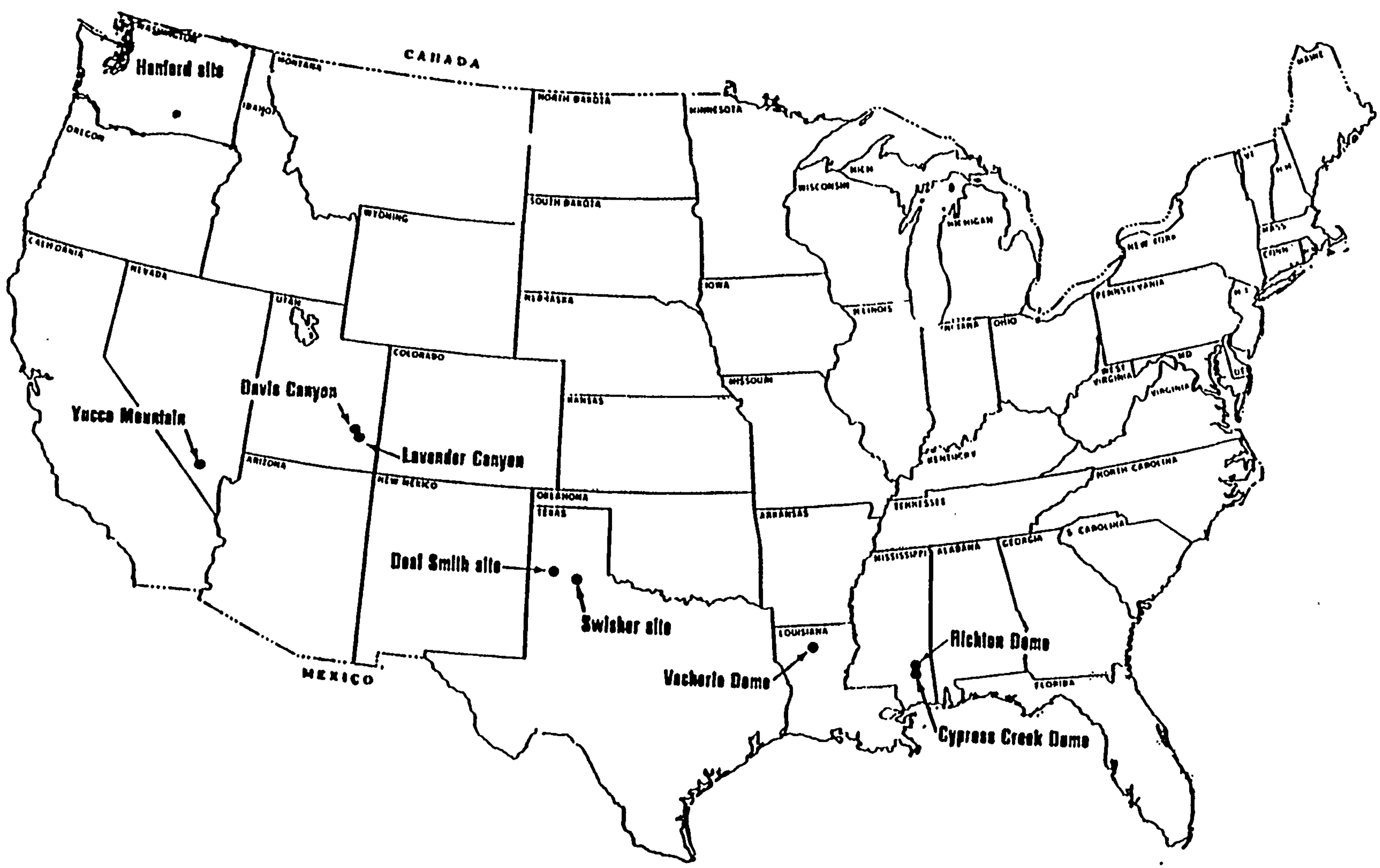


Fig. 6.1 Potentially acceptable sites for the first repository.

early 1986. Publication of the EAs was rescheduled to April 1986 as a result of this additional review. Together with the issuance of the EAs in May 1986, DOE nominated the reference repository locations at the following five sites as suitable for characterization: (1) the RRL, Hanford site, Washington; (2) YM; (3) Deaf Smith County site, Texas; (4) Davis Canyon site, Utah; and (5) Richton Dome site, Mississippi (DOE, 1986*d-h*).

When nominating these five sites, the DOE followed the six-part process in selecting sites as specified in the guidelines. Data in the EAs were instrumental in this process. A summary of this six-part process and the reasons the DOE gave in nominating the five sites for characterization are given in Appendix G.

## 6.7 RECOMMENDATION OF THREE SITES FOR CHARACTERIZATION

According to the NWPA, and consistent with 10 CFR Part 960, following DOE's formal nomination of five potentially acceptable sites, the Secretary was required to recommend to the President not fewer than three of these sites as candidate sites for detailed characterization. The NWPA required that an EA provide analyses and evaluations of available data relevant to the suitability of the 5 nominated sites.

The DOE developed an analysis described in *Multiattribute Utility Analysis of Sites Nominated for Characterization for the First Radioactive Waste Repository—A Decision-Aiding Methodology* (DOE, 1986*a*). This methodology makes use of data and analysis in the EAs in a decision process that allows for a complex set of objectives to be desegregated into its component parts for evaluation; this is followed by a reaggregation to determine a composite ranking of the nominated sites. At DOE's request, NAS and NRC reviewed this methodology and subsequently endorsed it (NAS and NRC, 1985).

Additionally, in arriving at a final order of preference, the DOE considered the provisions in the siting guidelines for diversity of geohydrologic settings and diversity of rock types. With respect to geohydrologic settings, the five sites nominated by the Secretary as suitable for site characterization provide the maximum diversity because each site is in a distinctly different geohydrologic setting. Therefore, a combination of any three of the five recommended sites will provide the maximum diversity in geohydrologic settings. However, to provide the maximum diversity of rock types, it would be necessary to select a RRL at the Hanford site, Washington (basalt); the YM site (tuff); and one of the salt sites at Deaf Smith County, Texas, Davis Canyon, Utah, or Richton Dome, Mississippi.

On the basis of the EAs and the previous considerations, on May 28, 1986, the Secretary recommended the following three sites as candidate sites for characterization (DOE, 1986*c*): Hanford, Washington (Appendix H); YM (Appendix I); and Deaf Smith County, Texas (Appendix J). Moreover, the Secretary made a preliminary determination that these three sites are suitable for development as geologic repositories consistent with the siting guidelines.

According to NWPA, the President may approve or disapprove the recommendations, permit the characterization to proceed by taking no action within 60-d, or delay his decision for 6 months if he feels that insufficient information is available. However, in a press release on May 28, 1986, DOE stated that President Reagan approved the undertaking of detailed studies leading to a complete characterization of the three sites.

## 6.8 SITE CHARACTERIZATION PLANS (SCPs)

The NWPA required DOE to issue SCPs as soon as possible after the recommendation of sites for characterization. These plans are required to include the following: (1) a description of the site; (2) details of the site characterization activities; (3) plans for decommissioning the site and for the mitigation of any significant adverse environmental impacts; (4) criteria to be used to determine the suitability of the candidate site for the location of a repository; and (5) any other information required by NRC. A detailed, annotated outline of the SCP was completed by DOE and approved by the NRC (DOE, 1987*b*). Initial drafts of the SCP were being prepared for each of the three recommended sites when the program was further focused by legislative action in December, 1987 (NWPAA, 1987). By this action Congress designated that the YM be studied in detail to evaluate suitability as the only candidate site for the first U.S. geologic repository for spent nuclear fuel and HLW and that investigations at the other two sites (Hanford and Deaf Smith County) be terminated. An SCP for the YM site was issued in December 1988.

## 6.9 TECHNOLOGY DEVELOPMENT

On May 28, 1986, the Secretary announced (DOE, 1986*c*) the postponement indefinitely of the search for a second repository because current waste projections indicated that such a repository would not be needed until well into the next century.

While site-specific work was thus discontinued, DOE expressed its intention to maintain a technology-development program relative to a second repository. The ultimate goal of this program was to determine the feasibility of selecting and evaluating sites by analytical procedures that do not rely on classical site-specific studies.

The program was to entail generic or non-site-specific evaluations of potential host rocks (crystalline rocks and sedimentary rocks other than salt) and the development of improved analytical approaches by which to evaluate geologic settings (not sites) regarding their waste-isolation performance. Experience from the first repository, especially in the area of performance assessments was to be integrated into this developing methodology, which included mathematical modeling and computer simulations as essential components.

## 6.10 NUCLEAR WASTE POLICY AMENDMENTS ACT OF 1987

The NWPAA was passed by Congress on December 22, 1987, as part of the Budget Reconciliation Act for fiscal year 1988 (Public Law 100-203) Title V. This amendment called for a major redirection of the nuclear waste program by directing the Secretary to phaseout and terminate site-specific activities at all candidate sites other than the YM site.

In addition to the selection of Yucca Mountain as the only site for continued investigation and characterization, the amendment also called for the following:

- Termination of all site-specific activities with respect to a second repository unless Congress specifically authorizes and appropriates funds for such activities.

- Phasing out and terminating all research designed to evaluate the suitability of crystalline rocks for a repository.

- Specified additional siting criteria to be used in the event that the Secretary considers any sites in crystalline rocks at some later time.

- Opportunity for the state of Nevada and Nye County to designate a representative to conduct on-site oversight of site-characterization activities, the expenses of such representatives to be paid out of the Waste Fund (Congressional intent regarding the funding policy for affected Indian tribe's needs clarification).

- A report to Congress on potential impacts on Nevada in 14 specified subject areas resulting from carrying out site characterization.

- Annulment and revocation of an earlier DOE proposal (EC-1022, 100th Congress) to locate a Monitored Retrievable Storage (MRS) facility subject to specified conditions that include establishment of an MRS commission; procedures in the event of a Notice of Disapproval by the governor or by an Indian tribe; and benefits to a state, Indian tribe, or affected units of local government.

- Establishment of the Office of Nuclear Waste Negotiator within the Executive Office of the President to be headed by a presidential appointed nuclear waste negotiator who is to (1) attempt to find a state or Indian tribe willing to host a repository or an MRS at a technically qualified site on reasonable terms and (2) to seek to enter into negotiations on terms and conditions of the United States with the governor of any state in which a potential repository site is located or with the governing body of any Indian tribe on whose reservation a potential repository site is located.

- Establishment of a Nuclear Waste Technical Review Board as an independent establishment within the Executive Branch for the purpose of evaluating the technical and scientific validity of activities undertaken by DOE after the date of *this Amendments Act*, including site characterization and activities relating to packaging or transportation of HLW or spent nuclear fuel. This Board is to report its findings, conclusions, and recommendations at least twice a year to the Congress and the Secretary.

- Additional requirements and restrictions related to transportation of nuclear waste.

- Establishment of an Office of Subseabed Disposal Research, which shall evaluate and make recommendations on specified aspects of subseabed disposal of spent fuel as an alternative technology for nuclear-waste disposal.

- Establishment of a university-based subseabed consortium to investigate technical and institutional feasibility of subseabed disposal.

- A study and evaluation of the use of dry-cask storage technology at the sites of civilian nuclear-power reactors for the temporary storage of spent fuel until such time as a permanent geologic repository has been constructed, licensed, and is capable of receiving spent fuel.

As a consequence of this Amendments Act, work on SCP and other activities was phased out and terminated for the Hanford site, the Deaf Smith County site, and the second repository program. The SCP for the YM site was completed and released in 1988 (see Sect. 6.9). A Technology Development Program was initiated (see Sect. 6.10), and conditions of the Amendment were carried out (such as the establishment of the MRS Commission and the Nuclear Waste Technical Reviews Board).

This event (passage of the NWPA of 1987) brings the chronology to a close and marks the start of a new era in which the program and its activities became more sharply focused than it had been at any other time in the past.

# 7. SUMMARY

Eminent scientists have been called upon throughout the course of investigations to review the issue of siting and to make recommendations for future studies. As early as 1955, NAS and NRC was commissioned by the AEC to assemble a group of earth scientists and engineers to review the concept of a geologic repository and to recommend the research, development, and exploration that would be needed. Since that initial work, NAS and NRC has convened several committees to review components of the Repository-Siting Program.

The experience and expertise of various federal agencies have also been used in site-related investigations for locating a geologic repository. The agency most frequently involved is the USGS, whose geologic and hydrologic investigations provided specialized data at most sites that have been considered. In addition, its ongoing review and assessment of the geotechnical aspects of repository siting were instrumental in developing some of the current siting policy. Perhaps the most publicized involvement of federal agencies occurred in the late 1970s when President Carter (Carter, J. E., 1978) convened the IRG (IRG, 1979), which consisted of representatives from 14 federal agencies who collectively reviewed the HLW program and recommended various measures that would ensure the safe isolation of these wastes.

To make use of the abundant resources available at the federal government's own national laboratories, DOE has used the services of many of those laboratories in various capacities related to repository siting. ORNL was the principal contractor to the government for nearly all waste repository work during the period 1955–1978. In addition, Lawrence Berkeley National Laboratory was instrumental in conducting in situ field investigations at Stripa, Sweden, and has directed the efforts to locate and construct a WIPP in southeast New Mexico, since 1975, and it has contributed to studies at the NTS and YM site . LLNL and LASL conducted in situ tests and other related investigations at YM and other sites at the NTS. Argonne National Laboratory, Pacific Northwest Laboratory, Brookhaven National Laboratory, and Idaho National Engineering Laboratory had supporting roles in various aspects and tasks of the repository-siting activities.

A policy of active participation by state and local organizations in the siting of geologic repositories has been pursued since the earliest years of repository work, starting with the KGS and other state agencies that were principal participants in the site-related investigations at Lyons, Kansas, during the mid-to-late 1960s. The KGS and other groups also conducted the supplemental site investigations in that state during the early 1970s, and their findings were influential in shaping the AEC's siting decisions at that time. As the site-related investigations expanded during the 1970s and 1980s, the roles of state and local organizations have increased dramatically in the technical as well as in the environmental and sociopolitical, aspects of the work. The extent of this latter participation is evident in the NWPA, as amended, in which the role of the affected states, Indian Tribes, and local governments in the siting is detailed.

The first siting work at Lyons, Kansas, was initiated in large part because of the need to dispose of alpha-contaminated waste. This effort resulted in the concept of a dual repository that would accommodate alpha-contaminated wastes separately from HLW. Because this concept strongly favored a site with an unused mine for hosting the waste and because rock salt was regarded at that time to be the most suitable rock for a repository, the Lyons site received considerable attention.

In the next phase of siting investigations, the concept of a dual-purpose repository was retained but because of opposition to the proposed site at Lyons, it was believed to be advantageous to continue the search for a geologic repository on government-owned land. This search led to the considerable site-related work in the bedded salt deposits of Southeast New Mexico. To promote assurances as to the safety of a geologic repository, the proposed facility was designed as a pilot plant. This design required the wastes to be emplaced in a retrievable mode and, thereby, relieved the public's concern for safety in case of any unforeseen events. The need for a repository for alpha-contaminated waste was satisfied in the mid-1970s when a site in the salt deposits of New Mexico was designated for defense waste other than HLW and was named the WIPP.

With the dual-facility concept abandoned, the search for repository sites took on a much broader scope both in the varied types of rocks considered for hosting the wastes and in the number and extent of geographic regions considered in the search. Thus, by the mid-1970s, siting investigations had grown to include the salt domes of the Gulf Coast as well as the anticlinal salt deposits in the Paradox Basin of Colorado and Utah. The bedded salts in the northeastern states were also being studied as were the salt beds in the Texas portion of the Permian Basin. Thick bodies of shale and clay that were believed to be potentially suitable for the storage-disposal of HLW were identified. Even chalk and limestone formations were examined. Crystalline rock studies were initiated at that time, while studies of argillaceous rocks were expanded to include argillite at the NTS and additional shales and clays. Volcanic rocks also received attention as evidenced by the new studies on tuff at the NTS and the reinitiated studies of basalt at the Hanford site.

This expanded program, which, at the time, was envisaged as the simultaneous development of multiple repository sites in various rock types throughout the country, led to the appointment of specialized management and technical development organizations to carry out the many site investigations and related activities. Although the organizational structure of the site-related work has changed from time to time to meet necessary modifications in the program, the management and technical development for siting repositories has remained consistent with budget outlays and has usually provided the institutional means to satisfy the objectives of the program.

To share knowledge with and to gain knowledge from the experiences and investigations of foreign programs also engaged in the siting of waste repositories, significant cooperative projects were initiated with Sweden and West Germany in the late 1970s. The Swedish work centered on joint participation in a series of underground tests in crystalline rocks at the abandoned Stripa mine in central Sweden. The Federal Republic of Germany (FRG) and the United States collaborated on a host of studies related to waste burial in rock salt. Much of that activity involved the Asse Mine in Lower Saxony. The United States also participated in other international efforts through assistance in the formulation of programs and policies and in the preparation of reports of the International Atomic Energy Agency (IAEA), International Energy Agency (IEA), and the Nuclear Energy Agency (NEA).

Although many issues and events have had some influence on the search for repository sites throughout the country, it is likely that no single factor has been instrumental in bringing the work to the current point. Rather, the siting problem has evolved through several stages of development that would be expected in light of the growth and importance of the nation's nuclear reactor industry and the general increase of environmental concerns that have arisen over the disposition of nuclear and other types of hazardous wastes. There was an increasingly negative reaction to this work by state and local parties from the early days of siting in Kansas, where a single site with an existing means for disposal of alpha-waste was proposed for a repository, to the later situation where as many as nine sites had been investigated and found to be potentially suitable for development (three of which were subsequently nominated for site characterization and one of which was later selected for characterization). This is so in spite of, but also in part due to, efforts to (1) formalize criteria (2) strengthen state and local participation in the decision-making process (3) conduct exhaustive investigations of the areas affected, and (4) expand greatly the number of rock types and regions throughout the country to be investigated for repositories.

Siting criteria have played an important role in the search for geologic repositories since the first major siting event was initiated in the late 1960s at Lyons, Kansas. Since then, a systematic approach was developed for siting geologic repositories which is well-financed and which is attentive to the many technical aspects of the problem and to state and public concerns. To the greatest extent practicable, this report addresses the technical factors that are important in siting a geologic repository for high-level radioactive waste.

It is disappointing that after more than 30 years of investigations, not one site in the world, to date, has been approved for construction and operation as a geologic repository for HLW. Undoubtedly, some very valuable operating experience could have been gained from an early startup of such a facility. However, it may be concluded that with so many developments in, interruptions of, and modifications to the nation's plans for disposal of these wastes over the past 34 years, if any repositories had been sited earlier, it is likely that they might not now be suited to handle today's wastes and would be out of compliance with current policy and regulations. This is especially true for criteria, public interfacing, and technical issues. For example, siting criteria evolved from the listing of a few generalized statements on such things as the depth and thickness of rock-salt formations in progress reports and other documents in the 1950s and 1960s to formalized geological criteria for determining the suitability of repository sites by the NAS and NRC and other groups in the 1970s. Even later, in the 1980s, the Secretary of Energy issued guidelines for recommendation of sites for repositories that specify detailed geologic considerations and criteria for site selection. Although state organizations and agencies were actively engaged in technical investigations related to siting a repository in Kansas in the late 1960s and 1970s, the level and degree of such effort were small in comparison to the consultation and participation of DOE with States and Indian Tribes which are decreed in the NWPA of 1982 and its Amendment in 1987. Finally, the depth and breadth of studies related to technical issues of siting in the 1950s, 1960s, and even the 1970s would now appear to be superficial to those used today. Some measure of these differences can be derived from the estimated total costs of $35 million for the Demonstration Repository at Lyons, Kansas, in 1971, to estimates of the costs at the Nevada site that may exceed those of the Lyons site by nearly two orders of magnitude.

The complexities of siting a geologic repository for HLW direct attention to a host of technical, political, and societal issues, which were not envisaged in the 1950s, 1960s, or even in the early 1970s. However, with the formation of the NWTS in 1976, the organization and structure were in place to develop the comprehensive plans and policies for siting that would culminate in 1982 with the passage of the NWPA.

The siting process for a geologic repository has, over the last three decades, evolved to the point at which the President and the Congress are principal participants in the process. Relationships of the federal government with the public and states are well defined, and technical criteria and site performance are set out in detail. Thus, it is apparent that if a geologic repository had been sited, constructed, or operated in the 1950s, 1960s, or 1970s, it would be inadequate for use by today's standards. Any emplaced waste surely would have had to be exhumed and reinterred. The notoriety and cost of such action would be great, as evidenced by recent experiences in hazardous waste cleanups and remedial actions at sites contaminated with low-level radioactive and hazardous wastes.

In the process of siting a geologic repository for HLW, many important technical issues have developed that influenced the course of action. These issues include (a) disposal in salt vs other rocks; (b) acceptable sites vs best site; (c) liquid vs solid waste forms; (d) dual repository (high-level and alpha wastes) vs single concept (HLWs); (e) existing excavations vs specially developed space; (f) private vs government-owned lands; (g) costs; (h) storage vs disposal; (I) alternatives to geologic disposal; (j) single site vs multiple sites; (k) one rock type vs multiple rock types; (l) reprocessed wastes vs spent fuel; (m) test, demonstration, or pilot repository; (n) evaluation system; (o) consolidated vs local project management; (p) federal preeminence vs state veto; and (q) regional preference vs national survey.

A number of key events occurred during the history of the siting process that were instrumental in governing the level and direction of efforts. These events are listed in chronological order and include:

1. At the Princeton Conference, NAS and NRC concluded that salt is the most-promising host rock—1955.

2. AEC developed processes to convert liquid wastes to solidified wastes—1958–1962.

3. AEC conducted studies in the Carey Mine, Hutchinson, Kansas, to determine feasibility of disposal of liquid wastes in salt—1961–1962.

4. The feasibility of disposal of high-level solid wastes in salt deposits was demonstrated through Project Salt Vault—1964–1967.

5. Lyons, Kansas, was selected as the tentative location for the nation's first "demonstration repository"—1970.

6. The AEC withdrew from the Lyons site and initiated studies to locate alternate sites in Kansas—1971.

7. AEC studied alternatives to the geologic option for disposition of wastes—1972.

8. AEC started a program of siting a pilot repository in rock salt deposits of Southeast New Mexico—1972.

9. The USGS became a principal investigator in the siting process—1972.

10. The search for a pilot repository was expanded to other salt bodies and rocks—1972.

11. Preliminary design studies were initiated for the RSSF—1973.

12. RSSF development was halted because of concerns that the concept did not provide a permanent solution to the problem—1973.

13. The GDEP was announced; it greatly expanded the siting activities for a geologic repository—1974.

14. ERDA superseded the AEC (1975) and announced the NWTS—1976.

15. Multiple repository sites in various rock types were investigated to satisfy the needs of NWTS—1976.

16. Formalized siting criteria were developed by ORNL, NAS and NRC, IAEA, and others—1976–1980.

17. To strengthen DOE's relationships with the affected states, peer review groups were established, including the GRG, State Planning Council, and the State Working Group—1976.

18. Project-management firms were hired to manage regional siting studies—1977.

19. Siting activities at the Hanford site and the NTS grew to the point at which they became separate and independently managed and funded projects—1977.

20. A major international cooperative venture was undertaken with Sweden and other countries to conduct tests underground in crystalline rocks at the Stripa Mine, Sweden—starting in 1977.

21. The multibarrier approach enhanced the concept of geologic disposal—1977.

22. DOE was created to replace ERDA and other organizations and effectively elevated the geologic-repository siting process to the attention of administrators at the highest levels of government—1977.

23. Michigan adopted a veto power over the siting of a geologic repository and effectively blocked the drilling of exploratory bore holes in the state—1977.

24. The IRG was established to help formulate a national policy for long-term management of nuclear wastes—1978.

25. President Carter's emphasis on technical conservatism strengthened the concept of geologic disposal—1978.

28. The decision was made to dispose of spent fuel rather than to reprocess it; number of repository sites reduced from six to two—1978.

29. A policy of "consultation and concurrence" was adopted by the federal government to increase participation in the siting process by the states, the Indian Tribes, and the public—1979.

30. Mined geologic disposal was selected as the most-suitable near-term option for the management of HLWs according to the draft generic EIS, 1979—and the final EIS—1980.

31. Congressional study of the management of HLW culminated in the passage of the NWPA, which was signed into law—January 1983.

32. A national survey of crystalline rocks (OCRD-1) was published—1983.

33. DOE issued national plan for siting high-level radioactive waste repositories—1983.

34. Nine potentially acceptable sites were identified by DOE—1983.

35. Draft siting guidelines were issued by DOE—1983—and final guidelines were published in the *Federal Register*—1984.

36. A DOE Mission Plan was submitted to Congress—1985.

37. A draft EA for the nine sites were issued—1984; the final three EAs were published—1986.

38. Five of the nine sites were nominated for site characterization; however, only three of those were recommended as candidate sites for characterization—1986.

39. President Reagan approved the recommendation of three sites for characterization—1986.

40. DOE developed the *Multiattribute Utility Analyses of Sites Nominated for Characterization for the First Radioactive Waste Repository, A Decision-Aiding Methodology*—1986.

41. A draft recommendation report that identified 12 potentially acceptable sites in crystalline rocks was released—1986.

42. The Secretary of Energy announced the decision to postpone indefinitely the search for a second repository in crystalline rocks—1986.

43. Outlines of SCP for the three approved sites were completed and approved by DOE—1987.

44. The Mission Plan Amendment was published—1987.

45. The NWPA was amended and, in compliance with that amendment, activities were terminated at all sites except YM—1987.

46. A final SCP for the YM was published—1988.

Since 1954, the siting process evolved from a well intended but subsidiary effort in civilian reactor development activities to a program that is currently funded and managed at one of the highest levels of government. In the last 3.5 decades, more than 60 regions, areas, or sites in nine different rock types have been investigated in the search for the nation's first geologic repository for HLW. These studies were, for the most part, undertaken to provide data relevant to the repository potential of a particular geographic location or rock type, but they now provide the background and basis for the current plans for siting.

Perhaps the greatest impediment to successful siting in all of the studies before 1982 was the underestimation of the magnitude of the siting problem. It is now apparent that the technical, societal, and political aspects of the siting process must be resolved in concert on both the local and national levels to effect a successful closure to this highly complex and important problem.

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# APPENDIX A.
# SOLIDIFICATION OF HIGH-LEVEL LIQUID WASTES

## A.1 INTRODUCTION

An international effort to develop processes to convert HLW to chemically stable solids for burial in selected geological formations, or storage in engineered surface structures, proceeded along with the work on geologic disposal. The diversified nature of this work can largely be attributed to the absence of firm criteria defining the characteristics of an acceptable solid waste form. As a consequence, a multitude of waste forms and processes for manufacturing them evolved. Laboratory work was directed at making and characterizing solid products ranging from melted or calcined high-level waste residues, to highly insoluble, fused ceramic materials. The engineering design and development of equipment with which to manufacture these products proceeded in parallel.

In the United States, several processes were developed at Brookhaven National Laboratory (Hatch et al., 1956; Regan et al., 1963), including one based on the use of montmorillonite clay for fixation of the radionuclides. A rotary-ball kiln and a screw calciner were developed to reduce the wastes to solid forms. Laboratory and pilot-scale work was carried out at Argonne National Laboratory (Loeding et al., 1961; Buckham and McBride, 1963) on a process for converting wastes to granular solids utilizing a fluidized-bed calciner. At ORNL a pot calciner process was developed that was capable of evaporating and calcining wastes in cylindrical steel pots which could serve as the final storage containers (Holmes et al., 1963). With appropriate additives to the waste, glassy solids of very low solubility could be produced. A process based on transport, and disposal resulted in a consensus that emphasis should be placed on the disposal of solid rather than liquid wastes.

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# APPENDIX B.
# SITE INVESTIGATIONS UNDER THE GEOLOGIC DISPOSAL EVALUATION PROGRAM

## B.1 BEDDED SALT

Investigations in the Permian Basin salt deposits narrowed in the early 1970s to the Los Medaños area of Eddy and Lea counties, New Mexico, where two exploration boreholes were drilled during the spring of 1974. These boreholes recovered 877 m (2,878 ft) and 911 m (2,988 ft) of core, much of it from the salt-bearing Salado Formation.

Core analyses, a complete suite of geophysical logs, and other geotechnical investigations, were undertaken to define the mineral resources of the area (Jones, 1973). Core analyses led to the discovery that one of the evaporite members in the Salado Formation contained sufficient potash to potentially support mining in the area (Jones, 1975). A core interval approximately 75 m (250 ft) thick was observed to contain near-commercial levels of two potash minerals, sylvite and langbeinite. The existence of gas cavities in the salt was also discovered during drilling operations. Immediately after total depth for one of the boreholes had been reached a blowout propelled drilling mud to an estimated height of 24 m (80 ft) above the wellhead area.

While concerns about potash resources and gas pockets were being investigated, a single-unit seismograph at the site recorded a strong shock whose epicenter was some 40 km (25 mi) northwest of the site. Because the Central Basin platform portion of the Permian Basin was characterized by tectonic stability and had no past history of major seismic events, a study to evaluate the cause of this earthquake amid the regional seismicity was undertaken by the USGS. The investigation indicated that the shock was probably related to a major rockfall (sudden subsidence of an entire block of rock above a large mined-out area) at the National Potash Company mine. Subsequent analysis would show that this earthquake was a natural seismic event unrelated to either that mine or any rockfall/collapse there (Caravella and Sanford, 1977).

### B.1.1 Salt Domes

The principal technical issues related to salt domes were the hydrologic and tectonic stability of specific domes. Initial studies by the University of Texas, Louisiana State University, and the USGS in Louisiana indicated that the following selected domes could be evaluated as (1) Kings, Rayburns, and Minden were hydrologically stable (2) Coeur Creek and Winnfield were unstable; and (3) Castor Creek, Coochie Brake, and Prices would require further study before their stability could be established (Martinez et al., 1975; Martinez et al., 1976).

### B.1.2 Salt Anticlines

Technical issues about salt anticlines centered on the hydrologic and tectonic stability of the Salt Valley structure in the Paradox Basin of Utah (Hite and Lohman, 1973). In 1974, the USGS began to map the previously undefined structural geology and stratigraphy of the area. They also studied the occurrence and nature of groundwater in the brecciated cap-rock zones of the anticlines and presented their findings in two open-file reports issued several years later (Gard, 1976; Hite, 1977).

During the GDEP, a cooperative agreement covering the management and disposal of radioactive waste was executed between the FRG and the United States (McClain et al, 1975). As part of this cooperative agreement, technical information in the area of repository site selection and evaluation began to be exchanged. This technical information included geologic, hydrologic, and engineering data on salt anticlines and the operating experience (more than seven years by 1974) of the FRG waste repository at the Asse II salt mine. As a point of information, it should be observed that the Asse facility is located in a salt dome, not a salt anticline.

**B.1.3 Shale**
Investigations concentrated on defining the relative permeability of shale formations, their stability of excavation, and their mineralogical, chemical and thermal characteristics. Included were investigations of the Pierre Shale and the Green River Formation. A study of liquefied petroleum gas storage caverns also revealed that many were sited in shales (Cobbs Engineering, 1975).

The Pierre Shale in the Northern Great Plains region of the United States was studied by the USGS to determine its regional geologic and hydrologic characteristics. Another study by two Colorado Schools of Mines faculties assembled, reviewed, interpreted, and documented all available information concerning the structural characteristics of the formation (Abel and Gentry, 1975). During this time, other groups examined the Green River Formation relative to (1) the suitability of oil shale formations in general for possible waste disposal; (2) the economics of the Green River Formation as a source of petroleum; and (3) the feasibility and economics of using this oil shale formations for possible waste disposal facilities (Netherland, Sewell, and Associates, Inc., 1975).

**B.1.4 Storage Caverns**
An investigation was initiated in 1974 to catalog and review feasibility investigations, construction histories, and operating experience of 75 mined storage caverns at 49 sites throughout the United States (Cobbs Engineering, 1975). Over half of these caverns were in shales, whereas the remainders were in rock salt, limestone and dolomite, and crystalline rocks. The purpose of the study was to relate the impermeability and stability of these storage cavities to physiographic subdivisions, stratigraphic factors, characteristics of overlying and underlying formations, regional and local geologic structures, and the regional and local hydrology. It was hoped that these features could serve as guides to identify rock formations having the requisite features for repository construction and waste containment. This study revealed that the caverns in shales had the smallest incidence of water seepage of any rock type.

**B.1.5 Dry Mines**

**B.1.5.1 Carbonate rocks**
The Barberton mine, about 10 km (6 miles) southwest of Akron, Ohio, was excavated in a limestone formation. The mine was known to be completely dry and to have structurally stable openings that extended over an area of nearly 2.5 $km^2$ within the subsurface. In 1974 an investigation of all pertinent and available geologic and hydrologic data on the mine was begun to determine the conditions that promoted the pronounced dryness (Byerly, 1976). An allied purpose of this study was to identify specific limestone or carbonate formations in other geologic regimes that might similarly be suitable for a site because of their dry conditions.

A related study on a series of mines in limestone in the Kansas City area was carried out in 1974 to determine the geologic and hydrologic characteristics of those subsurface settings that are characterized by dryness. The single most important factors responsible for the observed dryness were found to be impermeable shales that overlie the limestone beds (Goebel et al., 1975).

**B.1.5.2 Crystalline rocks**
An investigation of the driest mines in the Precambrian Shield of Minnesota, Michigan, Wisconsin, and neighboring Canada was carried out in 1974 and 1975 (Yardley, 1975). The primary goal of this work was to establish the geologic and hydrologic conditions that determined whether a mine would be dry or wet. The study examined such features as depth, rock type, overburden, faulting, and jointing, as water-controlling parameters.

## B.1.6 Other Igneous and Metamorphic Rocks

### B.1.6.1 Basalt

Studies on the basalts at the Hanford Reservation in Washington, which had been started in the 1960s, were reviewed and evaluated by the GDEP in 1974 (Piper, 1975). Special investigations were subsequently undertaken (1) to determine the local geologic and hydrologic conditions in the basalts, and (2) to evaluate the general potential of these rocks beneath the Hanford Reservation for containing high-level radioactive waste.

### B.1.6.2 Tuff

In collaboration with the USGS, the GDEP participated in a study to review and interpret the geologic data on the large number of excavations in the volcanic, plutonic, and metasedimentary rocks at the NTS (McClain et al., 1975). During the years since the site was first used for weapons testing, a large number of shafts, cavities, and tunnels used for an emplacement of nuclear devices, and numerous drill holes, had been made in a variety of rock types. A number of unique geohydrologic tests had been conducted in many of these excavations. These tests provided data on the tightness and stability of rocks such as granite and volcanic tuff at depth. The GDEP-USGS studies were designed to determine the factors that controlled the hydraulic conductivity and mechanical stability of these various rock types, especially as they related to the complex structural geology of the NTS.

### B.1.6.3 Metamorphic rocks

Investigations at the Savannah River Plant in South Carolina had been initiated in the early 1960s by the AEC to determine the feasibility of disposing of Department of Defense wastes into the deep metamorphic rocks (gneiss, schist, and quartzite) beneath the plant site (Christl, 1964). Clay-rich intervals within the overlying Coastal Plain sedimentary sequence were also studied. In 1974 the GDEP reviewed these earlier studies in order to incorporate their data into the background information for a broader study of these rocks.

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# APPENDIX C.
# OWI SITE INVESTIGATIONS

## C.1 BEDDED SALT

By 1978, OWI had reviewed the literature on salt deposits in the United States and identified the types and locations of those deposits (Johnson and Gonzales, 1978). This investigation detailed regional geologic, environmental, tectonic, and mineral resource factors pertinent to the use of the salt deposits for waste disposal. As a result of this study, some salt deposits previously not examined were included in future OWI investigations (see Fig. C.1).

### C.1.1. Michigan and Appalachian Basins

In the early 1970s, ORNL had undertaken investigations of the bedded salt deposits in the Michigan and Appalachian Basins (Landes, 1972; Landes and Bourne, 1976*a*, 1976*b*). This work was expanded under the direction of OWI. Specifically, areas were identified where disposal was anticipated not to conflict with oil and gas development. Other studies examined the geology of the Michigan Basin (Johnson and Gonzales, 1976) and the slat deposits of New York and Ohio in considerable detail (Stone and Webster Engineering Corp., 1978*a*, 1978*b*). However, as a result of social and political resistance, siting investigations in the Michigan Basin were discontinued in 1977.

### C.1.2 Permian Basin

Studies of the bedded salt in the Permian Basin of New Mexico were transferred to SNL where they evolved into the WIPP program for defense wastes. Investigations in the Texas Permian Basin, however, were expanded by OWI to include: (1) completion of a regional reconnaissance of the Anadarko, Palo Duro, and Dalhart Basins; (2) assessment of formation thickness, distribution depth, and structural features of these salt deposits, and (3) assessment of mineral resources seismicity and tectonics; and (4) hydrology and salt-dissolution as factors in site selection (Johnson, 1976). This study favored the Palo Duro and Dalhart Basins of Texas over the Anadarko Basin of Texas and Oklahoma for further investigation.

In 1976, the TBEG was contracted to conduct multidisciplinary geotechnical investigations on both the Palo Duro and Dalhart Basins. Their studies improved the understanding of (1) the stratigraphic relationships between the salt, anhydride, gypsum, dolomite, limestone, red beds that typically constitute a major salt bearing sequence; (2) the processes and means for quantifying the in situ dissolution of bedded salts as evidenced by salt-solution zones in wells and by erosional and collapse features on the surface; and (3) the regional groundwater flow system in each basin (Dutton et al., 1979; Gustavson et al., 1980). By the latter part of the OWI program, the TBEG investigations had progressed to the point whereby sites for stratigraphic test holes in Randall and Swisher counties were selected.

### C.1.3 Virginia River Valley, Nevada

A preliminary geologic study of the Virgin River Valley salt deposits in Clark County, Nevada, indicated that they have limited areal extent in an isolated basin (Netherland, Sewell, and Associates, Inc., 1977). Also, as a number of other unfavorable features for waste disposal sites were identified. Highlights of the study revealed the following (1) one-half of the salt body lies beneath the Overton Arm of Lake Mead, (2) the dry-land portion of the salt body has a thickness of less than 305 m (1000 ft) and covers an area less than 12 $km^2$ (4.5 $mile^2$), (3) tectonic activity exists in the area that is believed to be related to crustal readjustments following the filling of Lake Mead, and (4) a substantial area of the salt body lies inside the Lake Mead Recreation Area, which is governed by several federal, state, and local agencies who share regulatory responsibilities.

This study, however, identified several other salt deposit areas in Arizona and Nevada, namely Detrital Valley, Red Lake Dome, Luke Dome, and Morman Mesa area, and several plan lake areas of central Nevada,

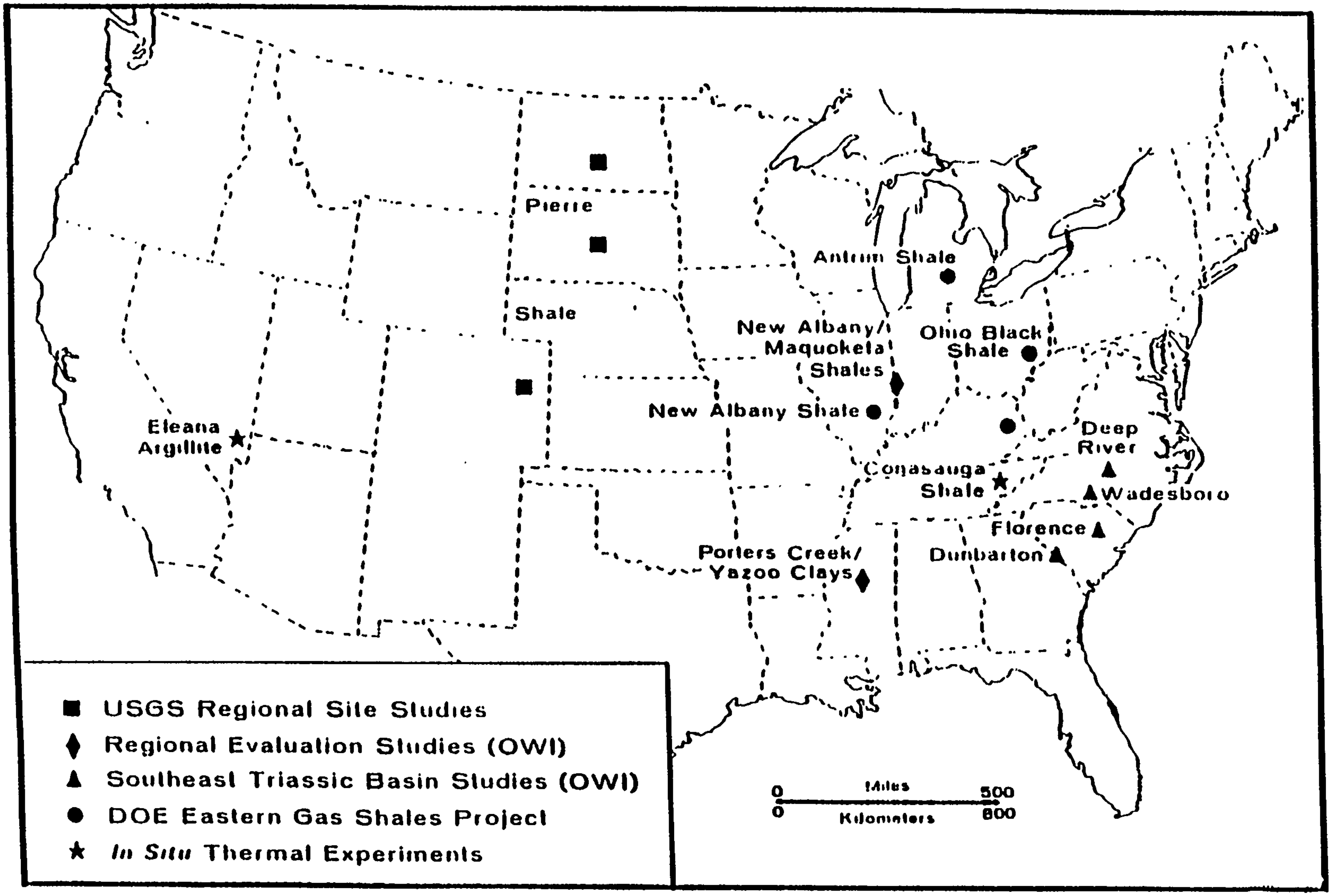


**Fig. C.1. Map of United States showing locations of field and subsurface studies and in situ thermal experiments conducted on argillaceous strata.**

as possibly meriting further study. However, other than limited data collected on the first three deposits (Johnson and Gonzales, 1978), no additional investigation of these other salt deposits was conducted by OWI.

## C.2 SALT DOMES

Investigations of Gulf Coast salt domes that were begun by the GDEP in 1974 were continued and expanded under the OWI program and included participation by Louisiana State University, the USGS, University of Texas, and others (Martinez et al., 1977, Krietler, 1978). Key technical issues identified in these investigations were (1) how to evaluate the tectonic stability of an individual dome (i.e., to determine if a dome is no longer moving) and (2) how to evaluate hydrologic stability (i.e., to determine if a dome is being dissolved by groundwater). Some important geologic and hydrologic questions posed were (1) what was the available space in a dome for repository construction, (2) what was the type and structure of the rocks that surround a dome, (3) what sediments were incorporated within a dome, (4) what length of time would be required for groundwater to migrate from the dome to the biosphere, (5) what significant mineral resources were present in the vicinity of a dome, (6) what was the effect of surface water flooding in the area of a dome, and (7) what constituted sufficient knowledge of the significant features of a dome (Martinez et al., 1978; Kreitler et al., 1978).

## C.3 ARGILLACEOUS ROCKS

The OWI siting investigations were largely confined to the Pierre Shale and to Mid-Continent shales (see Fig. C.1). Other shale studies included down-hole testing of the Conasauga Shale in Tennessee and the search for a suitable mine site in which to conduct in situ testing (Cobbs Engineering, 1976). These OWI efforts were intended to obtain information on the generic properties of specific types of shales.

### C.3.1 Pierre Shale

The USGS conducted a reconnaissance study of the Pierre Shale, which underlies a large part of North and South Dakota, eastern Montana, and eastern Colorado (Shurr, 1977). Using existing data, the USGS mapped geologic features, including depth to the base of the shale, shale thickness, overburden thickness, shale lithologies, and density of boreholes drilled for oil and gas. Three areas of potential interest were identified: (1) the eastern margin of the Williston Basin in North Dakota, (2) the southeastern margin of the Williston Basin in South Dakota, and (3) the eastern margin of the Denver Basin in Colorado.

These studies established the need to develop techniques for identifying and mapping linear features observed through satellite imagery, in order to determine if major basement faults, zones of fracture porosity, or areas of extreme lithologic variation exist within the areas of interest.

### C.3.2 Mid-Continent Shales

Investigators at Indiana University employed well records from the Indiana Geological Survey to develop maps of the lithology, distribution, and structure of the Ordovician Maquoketa Shale and the Devonian-Mississippian New Albany Shale in the Illinois Basin (Droste and Vitaliano, 1976). Areas in southern Indiana were identified as having thick sequences of these shales at depths from 305 to 915 m (1,000 to 3,000 ft) (Droste, 1976).

### C.3.3 Conasauga Shale

For many years, the Cambrian Conasauga Group shales that underlie the Oak Ridge Reservation in East Tennessee had been associated with the hydraulic fracturing and injection-disposal of low-level wastes mixed with cement slurries. In 1976, however, a series of shallow test holes was drilled into the Conasauga Group to test the hydrologic properties of several shale intervals. Cores were taken for laboratory measurements of intrinsic rock properties, principally thermal conductivity; later, down-hole heater experiments were conducted (Krumhansl, 1979). The Conasauga investigations were not technically siting studies, but were designed to gather information on the properties of typical Paleozoic shale.

### C.3.4 Black Warrior Basin Clays

Investigation of all rock sequences, Cambrian through Eocene, in the Black Warrior Basin of western Tennessee and northern Alabama and Mississippi was undertaken in 1976 (Mellen, 1976). This study described rock characteristics such as permeability, continuity, structure and seismic stability, and hydrologic association for the entire sedimentary sequence in the basin in order to discover thick, impermeable rock units. The Porters Creek Clay and Yazoo Clay in Mississippi were identified for further studies; however, no follow-up work was initiated.

### C.3.5 Triassic Basins Shales

OWI also studied the largely sedimentary sequences in the Triassic Basins within the southeastern states (Weaver, 1976). These studies were principally regional in nature, but did focus on the shale-dominated portions of the basin-fill sections. OWI further supported certain USGS drilling investigations within the Durham Basin in North Carolina where geophysical, borehole-logging, and hydrologic-testing methods were employed to evaluate that basin for non-radioactive waste disposal purposes. Data acquired by the USGS was shared with OWI investigators.

OWI lastly coordinated funding and gave technical guidance to studies conducted in the Southeast under the direction of the Savannah River Laboratory. In particular, a detailed regional study of all the Triassic Basins, and especially their shale-rich formations, was begun at this time although the final report was not issued until several years later (Dames and Moore, 1980).

### C.3.6 Nevada Test Site

Various igneous and metasedimentary rocks at the NTS were investigated during the OWI era. These included argillite and granite at several locations on the NTS and the early initial interest in volcanic tuffs. In situ thermal experiments on the Eleana Formation were also initiated during this time and provided information on the behavior of clay-rich intervals under simulated repository conditions (McVey et al., 1980). Planning for in situ testing of the Climax granite pluton was begun, although published accounts carry later dates (Ramspott et al., 1979).

Mapping, geophysical surveys, borehole testing, and other field studies on the NTS were largely undertaken by the USGS. In situ testing and related rock mechanics studies were conducted by several national laboratories, namely Lawrence Berkeley , Sandia, and Lawrence Livermore. Specific activities by all investigator groups are chronicled in the annual and monthly progress reports issued by the NWTS program.

## C.4 DRY MINES

In 1976 Lawrence Berkeley Laboratory began a study on mines developed in crystalline and argillaceous rocks which included (1) evaluation by in situ field studies of seepage in "dry" mines, (2) laboratory investigations of the physical properties of large rock samples, and (3) mathematical modeling studies of fluid flow in rock masses containing deformable fractures. The purpose of these investigations was to develop a rock property data base from in situ measurements in underground excavations. Results were published in the proceedings volume of the first (1978) Geotechnical Assessment and Instrumentation Needs symposium (Lawrence Berkeley Laboratory, 1979). Related hydrogeological considerations had also been reported by Witherspoon (Witherspoon,1977).

## C.5 CARBONATE ROCKS

### C.5.1 Mid-Continent Limestone

The study of the Barberton, Ohio, limestone mine resulted in a report that detailed the geologic features of the area and provided a description of limestone mining operations (Bylerly, 1976).

Investigators at the University of Missouri examined a limestone mine at Centropolis (near Kansas City) and other carbonate rocks of the Forest City Basin that had a potential for yielding dry excavations (Goebel, 1977). The Centropolis mine encountered water seepage through the shaft and from sandy units or nonconformities above or below the limestone. Further examination of the stratigraphy of the area indicated that movements of saline waters into the limestone were primarily along these sandy zones and nonconformities.

### C.5.2 Cretaceous Chalks

A review of thick chalk formations in the United States included the extensive Cretaceous Selma Chalk found along the Gulf Coast Plain from south-central Alabama to northeast Mississippi; the mid-continent Niobrara Formation in eastern Nebraska, central and western Kansas, and eastern Colorado; the Austin Chalk of east-central to northeast Texas; and other, less-developed Cretaceous and Tertiary chalks (Gonzales, 1975, 1977). Chalk's favorable characteristics as a waste disposal medium was found to be (1) low permeability and thus a general resistance to the penetration of water (2) reasonably thick and widespread (3) occurrence in regions of very low seismicity and generally with slight structural deformation (4) extremely fine-grained, which produces a measure of self-sealing plastic behavior, and (5) the absence of water within subsurface excavations as documented by a liquid petroleum gas cavern facility in south-central Alabama (Gonzales, 1975).

Chalk's negative characteristics were found to be (1) localized, small-scale fractures and faults (2) low compressive strength and a tendency to spall when excavated; (3) frequently associated with montmorillonitic clay, which has a tendency to lose or gain water and change in volume; (4) proximity of freshwater aquifers or petroleum reservoirs; and (5) penetrations by numerous petroleum wells, and in some areas, deep water wells.

## C.6 IGNEOUS AND METAMORPHIC ROCKS

The OWI Crystalline Rock program included studies of a number of different igneous and metamorphic rock types. The rocks investigated were distributed in several geographically and geologically diverse areas (Fig. C.2).

### C.6.1 Columbia River Basalts

In 1976 Atlantic Richfield Hanford Company (ARHCO) prepared a report summarizing prior work on the Columbia River Basalt Group in Washington state. Later in 1977, Rockwell Hanford Operations (RHO), successor to ARHCO, resumed geological studies to identify geochemical characteristics and to map the extent of basalts in the area of Sentinel Gap, eastern Umtanum Ridge, and in the Yakima Ridge-Rattlesnake Hills area.

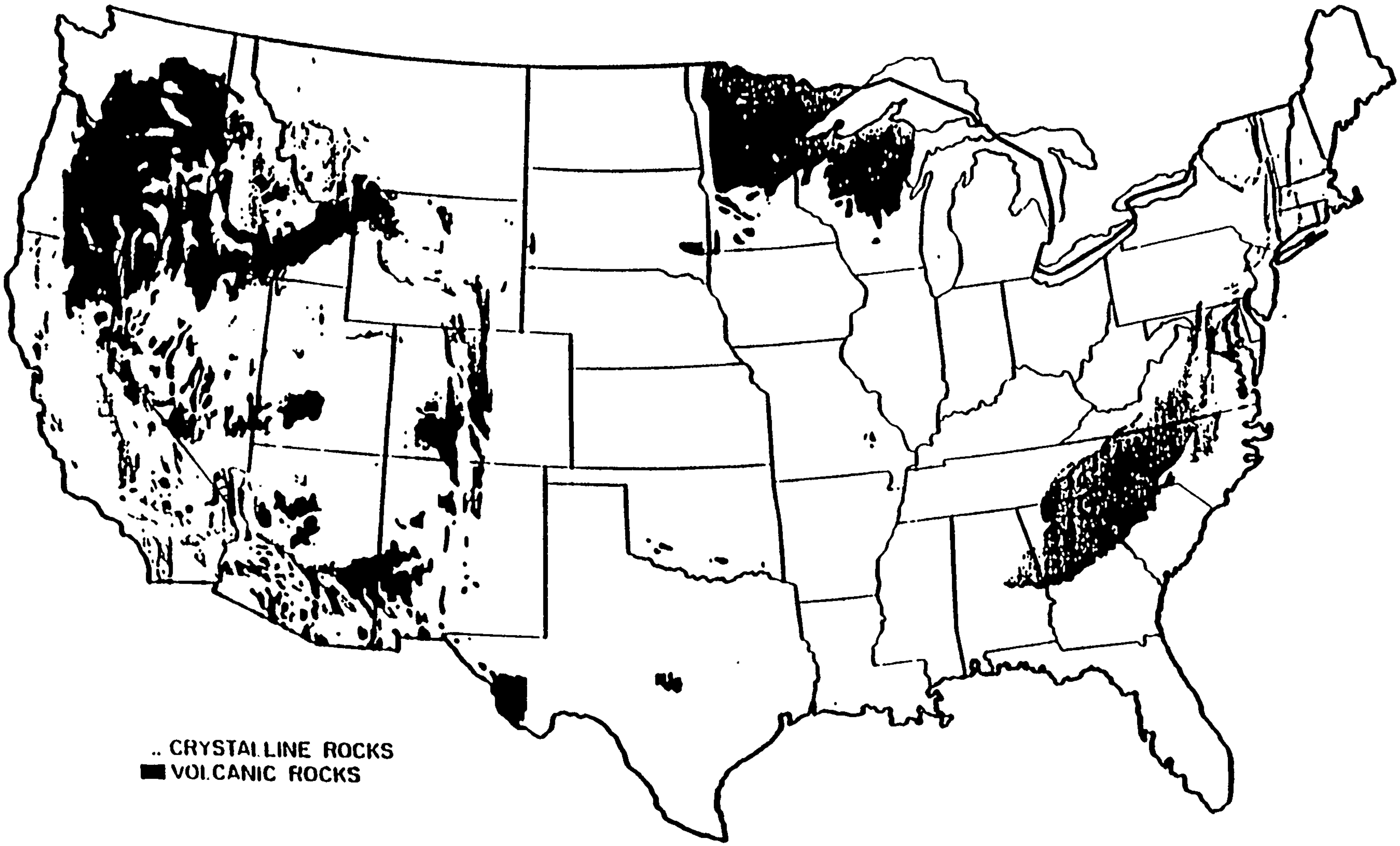


Fig. C.2. Exposed crystalline and volcanic rock in the United States.

### C.6.2 Rocks of the Precambrian Shield

Rocks of the Precambrian Shield in the Lake Superior region of northern Minnesota, Wisconsin, and Michigan were first evaluated as part of the GDE investigation of mined storage caverns. The OWI program continued a more general investigation to identify structures, seismic activity, zones of faulting, and other geologic features relating to tectonic stability of such igneous/metamorphic rocks in the United States and in the Maritime Provinces of Canada. The studies included granitoid rocks, such as granite and gneiss, are described here under the term "crystalline rocks," for which a separate and expanded program was subsequently created a few years later (see Appendixes D and L).

### C.6.3 Talc and Serpentinite Deposits

Talc and serpentinite metamorphic deposits in the eastern United States, which are confined principally to the Appalachian Mountain region extending from Vermont to Alabama, were examined as part of an OWI investigation (Wenner and Gonzales, 1975). Major deposits of talc associated with serpentinite and other ultramafic rocks, occur as discontinuous lenses tens of kilometers long and a few kilometers wide throughout the region. Three principal areas, the Gruvenor district of New York, the Chatsworth area of Georgia, and the Murphy Marble belt of North Carolina, were examined. This study concluded that most of these talc deposits appear to offer little potential as waste repository sites because the major bodies are either being actively mined or have been extensively excavated in the past and are susceptible to the inflow of groundwater.

However, talc-serpentinite bodies in the northern Appalachians in complexly folded and faulted terrains, tectonically inactive for more than 200 million years, might be more suitable (Wenner, 1976). Observations in several mines excavated in talc-bearing rocks in these areas indicate very low permeabilities compared to most other kinds of crystalline rocks. Groundwater influx in such mines, even at depths as shallow as 150 m (500 ft) occurs largely via artificial openings, in adjacent rock types, and in a few areas, by means of major fault zones.

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# APPENDIX D.
# ONWI SITE INVESTIGATIONS

## D.1 GULF COAST SALT DOMES

In 1978, ONWI's major effort on salt domes was in northern Louisiana, with investigations just beginning on salt domes in northeast Texas. By 1979, the activities in northeast Texas had progressed substantially, and the ONWI had begun investigations on three Mississippi domes.

Law Engineering Testing Company had previously been selected by OWI in 1979 as the GPM to manage all siting investigations in the Gulf Coast Salt Dome Region and Bechtel National, Inc. (later renamed Bechtel Group, Inc.) had been selected for a similar role in the environmental and socioeconomic area.

Regional studies had identified Vacherie and Rayburns Domes in Louisiana, Keechi, Palestine, and Oakwood Domes in Texas; Lampton, Richton, and Cypress Creek Domes in Mississippi as the most favorable domes for further investigation (Bechtel National, Inc. and Law Engineering Testing Co.,1980). Later, area studies conducted between 1979 and 1981 eliminated Keechi, Lampton, Rayburns, and Palestine Domes, either because of inadequate size, inadequate depth, or land-use conflicts (Bechtel Group, Inc. and Woodward-Clyde Consultants, 1982*b*). Siting investigations continued through 1985 on Richton, Vacherie, Cypress Creek, and Oakwood Domes, with Richton ultimately becoming the most favored.

## D.2 APPALACHIAN BASIN/SALINA SALT

The studies by ONWI on the Salina Group Salts (New York and Ohio) of the Appalachian Basin continued from the work begun earlier under OWI. Hydrologic study undertaken by the USGS, principally of the origin, composition, and occurrence of natural brines in the basin, was completed in late 1978 (Norris, 1978).

A compilation of the regional geology of both the Appalachian and Michigan Basins was also completed in 1978 by the GPM, Stone and Webster Engineering Corporation (SWEC) , but was not actually released until several years later. GPM, the Environmental Project Manager (EPM) firm for this region, together with the NUS Corporation, identified areas in southwestern New York and northeastern Ohio as having geologic and environmental characteristics that made them worthy of further evaluation (NUS Corp., 1979). No area was identified in Michigan, because neither the EPM nor the GPM had been granted access to state agency files and data, as they had been in New York and Ohio, a factor critical to the identification of favorable areas. As had occurred previously in Michigan under OWI, strong public objections developed and no further work was carried out on the salt beds of the Salina Group in this region.

## D.3 PARADOX BASIN

When the NWTS program was transferred from OWI to ONWI, field activities had already begun in the Utah portion of the Paradox Basin. The first of three deep borehole tests was drilled on the Salt Valley Anticline in Grand County in 1978, and the remaining two were completed in 1979. Other field activities were being pursued in the area of the Gibson Dome, 40 km (25 mi) south of Moab, and at Elk Ridge, 32 km (20 mi) west of Blanding in San Juan County. A third feature, Lisbon Valley, was undergoing preliminary investigations. Environmental Characterization Reports on the Paradox Basin study areas (Elk Ridge, Gibson Dome, Lisbon Valley, and Salt Valley) were written prior to 1981. In 1981, further studies on these four areas led to the recommendation of the Gibson Dome location (Bechtel Group, Inc., and Woodward-Clyde Consultants, 1982*a*). The Paradox Basin Characterization Summary Report selected both the Elk Ridge and Gibson Dome locations, but recommended that further characterization studies be undertaken at only the latter location (Bechtel Group, Inc., and Woodward-Clyde Consultants, 1982*b*).

## D.4 PERMIAN BASIN

As with work in other regions, ONWI continued studies in the Permian Basin of West Texas and Oklahoma that had been initiated under OWI. A Request for Proposals was advertised for a GPM firm and the resulting contract was issued to Stone and Webster Engineering Corporation. The TBEG continued as an important scientific subcontractor and the NUS Corporation served as the EPM contractor. (While the GPM procurement was progressing, two deep boreholes were drilled in Randall County, Texas.)

A few technical reports were issued under the auspices of the NWTS Program by the TBEG during this period, but generally work was carried on at a relatively low level. Ultimately, of course, work in this region resulted in the identification of the Deaf Smith County potential repository site that was recommended for detailed site characterization (see Appendix T).

## D.5 CRYSTALLINE ROCKS

A new group, Crystalline Repository Project Office, was established in the Chicago Operations Office to assume responsibility for studies of crystalline rocks. Argillaceous rocks did not fit the charter of either group, so this group of rocks was largely ignored for quite a period of time. Eventually, responsibility for the draft report that had been initially prepared for ONWI was transferred to the Oak Ridge Operations Office, through which it was revised and eventually published (Gonzales and Johnson, 1985).

## D.7 NATIONAL SCREENING

A third activity that was initiated in response to the IRG recommendation was the so-called "National Screening" activity. The objectives of this activity were (1) to systematically screen the contiguous 48 states to identify those portions that appear to be suitable for further investigation for repository sites, using a combination of environmental, geologic, and socioeconomic criteria, and (2) to establish a nationwide data base that might be used in further studies by DOE or in support of environmental documentation. The criteria that were to be utilized were those identified in the then-existing report on siting criteria (DOE, 1981). A proposal request for this activity was issued by ONWI and Woodward-Clyde Consultants was selected to perform the work. Although they prepared a program plan under a letter subcontract, no final contract was achieved and no further work was carried out.

## D.8 SCREENING OF THE BASIN AND RANGE PROVINCE

During the same time frame, an independent siting activity was initiated by the USGS for the Basin and Range Province, in cooperation with representatives of those states within this province (Arizona, California, Idaho, New Mexico, Nevada, Oregon, Texas, and Utah). This activity was financed entirely by USGS internal funds. The study was intended to be an evaluation for the geology and hydrology of one of the 10 physiographic provinces of the conterminous United States. The evaluation was to be made in a prototypical attempt to find potentially suitable geohydrologic environments for a repository from published reports and files of state agencies. The Basin and Range Province was selected for this feasibility study which identified areas worthy of further study, but did not identify potential repository sites. The major portion of this effort was completed by 1982 and resulted in 3 circular and 8 open-file reports, the latter of which were superseded in press. The circular reports were by Bedinger et al., (1984*a-h*), and Sargent and Bedinger, (1985). The *U. S. Geological Survey Professional Papers* were prepared by Bedinger, Sargent, Langer, and others.

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# APPENDIX E.
# NRC REGULATIONS

## E.1 DISCUSSON

As required by the NWPA, the NRC published the technical criteria for disposal of high-level waste in geologic repositories (NRC, 1983). These criteria, designed to implement the EPA regulations*, defined the bases for licensing of repositories and provided guidance on the performance objectives and siting criteria for the repository.

The NRC requires a multiple-barrier approach to achieve the EPA's isolation performance standard; two major engineered barriers (waste package and the underground facility) in addition to the natural barrier provided by the geologic setting were identified. The NRC specified that the engineered barrier system should be designed so that (1) the containment of high-level waste within the packages will be substantially complete for a period of 300 to 1,000 years after permanent closure of the repository, and (2) the release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed $10^{-5}$ per year of the inventory of that nuclide calculated to be present at 1,000 years following permanent closure. An important factor in selecting the geologic setting was the requirement that the repository be located so that the groundwater travel time from the disturbed zone of waste emplacement to the accessible environment be at least 1,000 years.

The siting criteria provide sets of favorable and potentially adverse conditions that must be considered in the repository siting process. The favorable conditions are:

1. Nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes operating within the geologic setting during the Quaternary Period that would not adversely affect the ability of the repository to isolate the waste.

2. Hydrogeologic conditions in the saturated zone that provide (a) a host rock with low permeability, (b) a downward or dominantly horizontal hydraulic gradient in the host rock and surrounding hydrogeolic units, and (c) a low vertical permeability and hydraulic gradient between the host rock and the surrounding hydrogeologic units.

3. Geochemical conditions that (a) promote precipitation or sorption of radionuclides, (b) inhibit the formation of colloids and complexes that increase the mobility of radionuclides, or (c) inhibit the transport of particulates, colloids, and complexes.

4. Mineral assemblages with ion-retardation capabilities that are not unfavorably affected by the anticipated thermal loading of the repository.

5. Conditions that permit the emplacement of waste at a minimum depth of 300 m (985 ft) from the ground surface.

6. A low population density within the geologic setting and a controlled area that is remote from population centers.

7. Groundwater travel time from the disturbed zone to the accessible environment that substantially exceeds 1,000 years.

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*The EPA final rule was published in 1986 but was subsequently remanded to EPA by court action. Current projections are that it will be several years before EPA is again ready to promulgate this standard.

8. For disposal in the unsaturated zone, hydrogeologic conditions that provide (a) a water table sufficiently below the repository that saturated voids do not encounter the underground facility, (b) a low moisture flux in the host rock and surrounding units, (c) a laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit or divert downward moving water to a location beyond the limits of the underground facility, (d) a host rock that provides for free drainage; or (e) a climatic regime in which the average annual precipitation is a small percentage of the average annual evapotranspiration.

Twenty-four conditions are listed that would adversely affect repository performance and, consequently, are regarded by the NRC as unfavorable factors in siting a repository. The list includes such factors as enhanced potential for natural disruptive events or human intrusion, unfavorable geologic or hydrogeologic conditions, undesirable groundwater characteristics, and geomechanical properties of the host rock that may affect mining and operational safety.

## E.2 REFERENCE

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# APPENDIX F.
# EPA STANDARDS

## F.1 DISCUSSION

The EPA is authorized to promulgate environmental standards for the management and disposal of spent-fuel and high-level, and TRU wastes. In September 1985, following a rather extensive period of technical development, review, and public comment, the final rule was published (EPA, 1985). This rule established several sets of requirements for disposal that are relevant to repository siting considerations:

1) **Containment requirements.** Limit the total projected release of specific radionuclides to levels that are projected to cause no more than 1,000 premature cancer deaths over an ensuing period of 10,000 years.

2) **Assurance requirements.** Mitigate the consequences arising from uncertainties in the performance of disposal systems over 10,000 years by incorporating the following principles:

   a. Active institutional controls of a disposal site cannot be relied upon for more than 100 years following disposal.
   b. Disposal options must be monitored to detect substantial changes from the expected performance until it is determined that no significant concerns need to be addressed by further monitoring.
   c. The sites of disposal systems must be identified by permanent markers, widespread records, and other passive institutional controls.
   d. Disposal systems must use several different types of barriers, both engineered and natural, to isolate the wastes from the environment.
   e. Sites for disposal systems must be selected to avoid places where resources have been mined, where there is a reasonable expectation of exploration, or where there is a significant concentration of any material not otherwise available.
   f. Retrieval of most of the wastes must not be precluded for a reasonable period after disposal.

3) **Individual Protection Requirements.** Limited annual radiation exposures to members of the public from the disposal system to 25 mrem to the whole body and 75 mrem to any critical organ for 1,000 years after disposal.

4) **Groundwater Protection Requirements.** Limit, for 1,000 years, the increases in concentrations of radioactivity in waters to no more than 15 pCi/L of alpha-emitting radionuclides and to no more than the combined concentrations of beta/gamma emitting radionuclides that would produce an annual dose equivalent greater than 4 millirem if individuals consumed all their drinking water from that groundwater.

## F.2 REFERENCE

U.S. Environmental Protection Agency, Sept. 19, 1985. *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes,* Code of Federal Regulations, Title 40, Part 191, U.S. Environmental Protection Agency, Washington, D.C.

# APPENDIX G.
# REASONS FOR DOE'S IDENTIFICATION OF NINE POTENTIALLY ACCEPTABLE SITES

## G.1 NON-DOE LANDS

As a result of the screening activities that took place during the 1960s and 1970s, four regions were identified as being suitable to host a nuclear waste repository with respect to the depth and thickness of underlying salt formations. These regions include the following (Pierce and Rich, 1962; Johnson and Gonzales, 1978):

1. The Salina Group bedded salt in the Michigan and Appalachian Basins of southern Michigan, northeastern Ohio, western Pennsylvania, and southwestern New York (also called the Salina Basin in some literature);

2. The Gulf Coastal Plain in Texas, Louisiana, and Mississippi, containing salt domes;

3. The Permian Basin of southwestern Kansas, western Oklahoma, western Texas, and southeastern New Mexico, containing bedded salt; and

4. The Paradox Basin of southeastern Utah, southwestern Colorado, and northwestern New Mexico, containing bedded salt that has been partly deformed into various anticlinal folds.

These four regions served as the starting point for the stepwise succession of surveys discussed in Section 5 of the text and Appendixes G and I. However, study of the Salina Group salts (Item 1 above) was deferred when the siting process reached the location survey phase due to state/federal politics. Thus, only the Gulf Coastal Plan, the Permian Basin, and the Paradox Basin were investigated further.

### G.1.1 Gulf Coastal Plan

In an initial screening made by the USGS, nearly half of the more than 500 known and inferred salt domes in the Gulf Coastal Plain were eliminated from consideration because they were located offshore. Of those remaining, the USGS identified 36 as potentially acceptable for hosting a geologic repository and another 89 as worthy of further study (Anderson et al., 1973). The screening factors used by the USGS were: (1) depth to the top of the dome and (2) present use for cavern storage or hydrocarbon production.

Regional studies were made of the remaining 125 salt domes (36+89) by the GPM Firm. Consideration of (1) depth of salt (2) lateral extent cross-sectional (area) of salt mass at repository depths; and (3) existing competing uses, led the GPM firm to recommend the following 11 domes as potentially acceptable: (1) Vacherie, (2) Rayburn's, (3) Goochie Brake, (4) Richton, (5) Lampton, (6) Cypress Creek, (7) Boggy Creek, (8) Keechi, (9) Mount Sylvan, (10) Oakwood, and (11) Palestine. These recommendations were released in a draft report which, because of extensive revisions was not published in final form until three years later (Law Engineering Testing Company, 1978; 1981). In the recorded citations of recommended domes in reports by the GPM (Bechtel National, Inc., and Law Engineering Testing Co., 1980) Brooks dome in the East Texas Study area was included whereas Coochie Brake dome in the North Louisiana Study area was not. Thus, in fact, 12 domes were named in this early screening effort. Coochie Brake was dropped because it was the deepest of those selected, there were concerns about its subsurface configuration, and the cost of developing a repository at those depths >913 m (3,000 ft). Brooks had been recommended by previous studies (Anderson et al., 1973; Netherland, Sewell, and Associates, 1975), and thus was included, but only for a short time.

Of the 11 domes that emerged from this somewhat confusing selection process, three were dropped for environmental reasons; that is, Brooks, because it was overlain by Lake Palestine; Mount Sylvan because it was too near the Tyler urban area; and Boggy Creek, because it was overlain by the Neches River (Bechtel

National, Inc. and Law Engineering Testing Company, 1980). A fourth dome, Palestine, in Texas, was eliminated somewhat later due to concerns over the development of sinkholes (subsidence features) at the land surface caused by the solution mining of the salt (Patchick, 1980).

The remaining seven domes, namely Rayburn's and Vacherie domes in Louisiana; Cypress Creek, Lampton, and Richton Domes in Mississippi; and Keechi and Oakwood Domes in Texas, were then subjected to area studies. On the basis of site-performance criteria (Battelle, 1981), which included geologic, hydrologic, geochemical, demographic, environmental, and socioeconomic factors, Keechi, Rayburn's, and Lampton Domes were eliminated (ONWI, 1982). The single most restrictive factor in eliminating these domes was the lateral extent of the host rock such that a buffer zone of at least 245 m (800 ft) was present. A prescribed waste loading was the basis for selecting the width of the zone. The Oakwood Dome was eliminated from further consideration because of nearby petroleum exploration and the sizeable number of boreholes that penetrated the salt overhang beneath which petroleum reserves were known to exist (Jackson and Seni, 1984).

In February, 1983, as a result of these studies and decision, DOE identified Cypress Creek, Richton, and Vacherie Domes as potentially acceptable sites from the Gulf Coastal Plain Region.

### G.1.2 Paradox Basin

To identify areas for further investigation, the Paradox Basin was screened by applying the following factors: depth and thickness of salt, mapped faults, other evidence of recent geologic instability, zones of groundwater discharge, significant resources, potential for flooding proximity to urban areas, and the presence of certain dedicated lands. This resulted in the identification of four areas for further study: Gibson Dome, Elk Ridge, Lisbon Valley, and Salt Valley (Battelle, 1981; Bechtel National, Inc. and Woodward-Clyde Consultants, 1982*b*).

The screening factors judged to have the strongest potential for differentiating possible locations within these four areas were depth to salt, thickness of salt, proximity to faults and boreholes, and proximity to the boundaries of dedicated lands (Bechtel Group, Inc. and Woodward-Clyde Consultants, 1982*a*). With the use of these factors, Salt Valley and Lisbon Valley were deferred from further consideration because all areas that had adequate depth to salt were too close to zones of mapped surface faults, and for Lisbon Valley were too close to existing boreholes. The 1982 Location Recommendation Report cited above (Bechtel National, Inc. and Woodward-Clyde Consultants, 1982*b*) identified one location in the Gibson Dome area and one in the Elk Ridge area.

Additional comparisons of the Gibson Dome and Elk Ridge locations were made on the basis of more-refined criteria, the most critical of which were thickness of salt, the thickness of shale above and below the depth of a repository, the minimum distance to salt dissolution features, archeological sensitivity, and site accessibility. The Gibson Dome location was selected as the preferred location because of the number and relative importance of favorable factors (Bechtel Group, Inc., and Woodward-Clyde Consultants, 1982*a*).

Three sites within the Gibson Dome location were identified for further evaluation: Davis Canyon, Lavender Canyon, and Harts Draw. From a study of the visual aesthetics (Bechtel Group, Inc., 1984), Harts Draw was eliminated because it affords a greater total area of visibility. In February 1983, Davis Canyon and Lavender Canyon were identified as potentially acceptable sites in the Paradox Basin.

### G.1.3 Permian Basin

In 1976, an evaluation was made of Permian salt deposits in the Texas Panhandle and western Oklahoma for underground storage of radioactive wastes (Johnson, 1976). Three sub-basins were considered in this early screening effort, namely the Anadarko, Palo Duro, and Dalhart Basins. The Delaware Basin was not considered for a civilian-waste site because it had already been selected for the WIPP for radioactive defense wastes. Each of these screened sub-basins contain salt beds of adequate thickness and depth. The Palo Duro and the Dalhart basins had much less potential for oil and gas production; neither had been penetrated as extensively by drilling as had the Anadarko Basin. Because of these resource considerations, the Palo Duro and Dalhart Basins were judged to be preferable and were recommended for further study (Johnson, 1976). The screening factors that contributed to the selection of the Palo Duro and the Dalhart basins include: (1) the depth and thickness of salt, (2) seismicity, (3) known oil and gas deposits, (4) the presence of exploratory boreholes, and (5) evidence of salt dissolution.

Six locations in various parts of Deaf Smith, Swisher, Oldham, Briscoe, Armstrong, Randall, and Potter Counties, Texas, were judged to have met screening criteria developed to define locations with favorable geologic and environmental characteristics. These six locations were then screened by factors relating to geomorphology, the presence of natural resources, flexibility in repository siting, the number of boreholes, population density, and land-use conflicts. As a result of this screening, the DOE selected two locations that seemed to have the greatest likelihood of containing a suitable site: northeastern Deaf Smith and southeastern Oldham Counties, and north-central Swisher county (Battelle, 1983).

After identifying parts of these two counties as acceptable sites in early 1983, in response to external review comments, the DOE subsequently narrowed the size of the two sites to be considered at each location (DOE, 1984).

## G.2 DOE LANDS

During the period when the DOE was developing a National Siting Plan, a number of approaches were discussed on how to initiate the screening studies. Although each of these separate approaches used common steps to evaluate specific sites, they differed in the selection of the geographic starting points for the sequence of site-screening surveys. One approach, the one that has been discussed to this point, identified large, multi-state regions of the country overlying geologic formations of potential interest. Another approach, adopted by the DOE, investigated land already owned by the federal government and committed to nuclear activities. This approach defined current land use as a basis for identifying areas for additional study. On this basis, the DOE initiated siting studies at federally owned land tracts in Nevada at the NTS and Washington at the Hanford Site. This approach, termed the land-use approach, was also recommended by the Comptroller General and the Congress (Comptroller General of the United States, 1979, and Congressional Record, 1979). Land use was the beginning basis for this screening of federal lands although subsequent progression to smaller land units was based on evaluations of geologic and hydrologic suitability and environmental factors.

### G.2.1 Hanford Site

The geologic and hydrologic characteristics of the Pasco Basin were studied under the Defense Waste Management Program conducted between 1968 and 1972 (Atlantic Richfield Hanford Company, 1976). Since 1977, the DOE has continued to study the geologic and hydrologic characteristics of the Pasco Basin, concluding that (1) some of the basalt flows in excess of 2,100 ft below ground are sufficiently thick to accommodate a geologic repository (2) the slow deformation rates of the basalt ensures long-term integrity of a repository at the Hanford Site; (3) the potential for volcanism at the Hanford Site is very low; and

(4) geochemical reactions between the basalt rock, groundwater, and the waste are favorable for long-term isolation.

The reason that the Pasco Basin was selected for screening was to provide a greater scope from which to evaluate processes that could potentially impact the Hanford Site and to determine whether or not any superior sites existed in the natural region outside of, but contiguous with, the Hanford Site (Woodward-Clyde Consultants, 1980).

An area in the west central part of the Hanford Site was identified as a candidate, satisfying criteria relating to the following factors (1) fault rupture, (2) ground motion, (3) aircraft traffic (4) ground transportation, (5) operational radiation released from nuclear facilities at the Hanford Site, (6) protected ecological areas, (7) culturally important areas, and (8) site-preparation costs.

Nearly half of this candidate area was eliminated during the next screening step to define potential locations on the basis of fault rupture, flooding, ground failure, erosion, the presence of hazardous facilities, induced seismicity, and site-preparation costs.

All the locations lying outside of the Hanford Site were eliminated on the basis of land use, hydrologic conditions, and the subsurface orientation of the basalt bedrock. After this process, five potential locations remained, all within the boundaries of the Hanford Site.

On the basis of an evaluation of 23 parameters chosen from criteria proposed by several sources (NRC, ONWI, and NAS), nine candidate sites were identified from among the five locations. Seven of these were located within the bend of the Cold Creek Syncline. Because the other two were closer to the Columbia River and were not technically superior, they were eliminated. However, three additional sites were identified that were largely superimposed on parts of the original 7 sites in the Cold Creek Syncline, thus yielding a total of 10 sites worthy of further study (Rockwell Hanford Operations, 1980).

Because these ten, partly overlapping, candidate sites were considered indistinguishable by routine ranking, decision analysis was used to identify the best site (Woodward-Clyde Consultants, 1981). This formal procedure resulted in the identification of two approximately coincident sites that rated higher than the others. Consequently, these two sites were combined and designated "the RRL." The decision criteria used in the formal procedure were derived from some eleven siting factors that considered geologic, hydrologic, environmental, and ecological circumstances. In February, 1983, the RRL was identified by the DOE as a potentially acceptable site.

### G.2.2 Nevada Test Site

At nearly the same time that the DOE began considering the NTS on the basis of land use, the USGS suggested that the NTS represent a potentially promising land area to be investigated for a repository site because (Dudley, 1977):

a) groundwater does not discharge into rivers that flow to major bodies of surface water,
b) flow paths are long between potential repository locations and groundwater discharge points,
c) geochemical characteristics of the rocks occurring at the NTS are favorable for waste isolation,
d) the amount of moving groundwater is low.

Since the primary purpose of the NTS is nuclear weapons testing, an ERDA task group was formed to determine whether or not compatibility could be achieved between weapons testing and a nuclear waste repository. It was determined by this group in 1978 that a repository located in other than the southwestern portion of the NTS might be incompatible with weapons testing. Thus, the program focused attention on the area in and around the southwestern corner of the NTS, subsequently called the Nevada Research and Development Area (NRDA). Other lands that were subsequently evaluated included some controlled by the Bureau of Land Management west and south of the NRDA and a portion of the Nellis Air Force Range west of the NRDA.

A preliminary list of five potential sites was compiled in August 1978 in and near the southwestern part of the NTS. These areas included Calico Hills, Wahmonie, Yucca Mountain, Skull Mountain, and Jackass Flats. The USGS determined that the first three exhibited the most promise and concentrated their exploration there. Consideration of the Calico Hills was suspended in the spring of 1979 because deep drilling failed to encounter a hypothesized granitic body there (Maldonado et al., 1979). Other studies showed that a Eleana Formation (argillite) there was structurally too complex (Hoover et al., 1982). Wahmonie was also eliminated from consideration in the spring of 1979 because geophysical studies and surface mapping indicated that the underlying granite may not be large enough for a repository, that the granite within reasonable depths probably contained economic deposits of precious metals, and that the highly fractured/faulted rock could allow vertical movement of groundwater (Smith et al., 1981; Hoover et al., 1982).

At YM, surface mapping showed the existence of a relatively undisturbed structural block, potentially large enough for a repository. In 1978, an exploratory hole confirmed the presence of thick sequence of volcanic tuff, much of it rich in sorptive zeolite minerals (Spengler et al., 1979).

In 1979, the NAS Committee for Radioactive Waste Management informally supported the concept of investigating tuff as a repository host rock (Gloyna, 1979). In addition, the USGS pointed out the considerable advantages of locating a repository in the unsaturated zone and recommended that attention be focused on Yucca Mountain in a letter dated February 5, 1982, to the NVO (Robertson, 1982).

A more formal analysis was begun in 1980 to evaluate whether or not YM was appropriate for further exploration. This formal analysis was consistent with the area-to-location phase of site screening described in the 1982 National Siting Plan. The formal decision analysis procedure (Sinnock and Fernandex, 1984) was applied to 15 potential locations, concluding YM was preferred. In addition, several potentially suitable disposal horizons were identified in both the saturated and unsaturated zones; the final selection was Topapah Spring Tuff (Johnstone et al., 1984). YM was identified by DOE as a potentially acceptable site in February 1983.

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# APPENDIX H.
# REASONS FOR DOE'S NOMINATION OF FIVE SITES FOR CHARACTERIZATION

## H.1 DISCUSSION

In nominating five sites, DOE followed the six-part process in selecting sites as specified in the 1984 Siting Guidelines. This appendix is largely paraphrased after several early sections contained within the final EA (Department of Energy, 1986*a–e*). Because of this, no additional reference citations are made.

The first step requires DOE to evaluate the potentially acceptable sites in regard to the disqualifying conditions. According to Sect. 2.3 of the final EA, the evidence does not support the disqualification of any of the nine potentially acceptable sites.

The second step mandates that the potentially acceptable sites be grouped according to their geohydrologic settings. Table H.1 shows the nine potentially acceptable sites contained within five distinct geohydrologic settings as defined by a USGS geohydrologic classification.

Step three requires DOE to select, from the geohydrologic settings that contain more than one potentially acceptable site, the preferred site on the basis of a comparative evaluation of all potentially acceptable sites in that setting.

For the Columbia Plateau, the RRL at the Hanford Site is the only potentially acceptable site identified. Likewise, YM is the only potentially acceptable site identified in the Great Basin.

For the Permian Basin, DOE selected the Deaf Smith County site over the Swisher County site because at the Deaf Smith site (1) a downward or predominately horizontal groundwater gradient is present and (2) it is farther from highly populated areas than is the Swisher County site.

In the Paradox Basin, DOE chose the Davis Canyon site over the Lavender Canyon site because part of the latter site extends into the Bridger Jack Mesa Wilderness Study Area, which is an area under review for possible inclusion in the National Wilderness System. The Lavender Canyon site would require, in addition to Congressional action needed to withdraw public land permanently, a Congressional determination of the status of the Wilderness study area. Because the time frame for such Congressional action was not scheduled and could thus delay program activities, DOE considered the Davis Canyon site to be more favorable. Otherwise, the differences between these two sites are minor.

Within the Gulf Coastal Plain, DOE selected the Richton Dome site over the other two salt domes (Vacherie and Cypress Creek) because of its ability to assure better compliance with the waste-isolation requirements. The rationale for this decision considered these points:

1. The significantly larger size of the Richton Dome allows significant flexibility in the location and design of the underground facility so as to ensure waste isolation.

2. There is an absence of known collapse features suggestive of dissolution activity.

3. There is an absence of previous subsurface mining or resource extraction within the site that could affect containment or isolation.

4. There is limited potential for flooding of the dome area and minimal requirements for the alteration of existing drainage during the construction of the repository.

5. There is an absence of projected land ownership conflicts that cannot be successfully resolved through voluntary agreements or legal proceedings.

The reasons why the Vacherie Dome was expected to be less favorable as a repository site with respect to waste containment and isolation were the following:

1. The limited lateral extent of the host rock at the proposed repository depth would necessitate a multiple-level repository.

2. The presence of a collapse feature above the dome is suggestive of host-rock dissolution.

3. There is a potential for flooding in the area of the dome and a need for stream diversion during repository construction.

The reasons why the Cypress Creek Dome was expected to be less favorable as a repository site with respect to waste containment and isolation were the following:

1. The limited lateral extent of the host rock at the proposed repository depth would necessitate a multiple-level repository.

2. The presence of a topographic depression above the dome is suggestive of host-rock dissolution.

3. The producing oil and gas wells that exist on one flank of the dome could affect waste containment and isolation.

4. Congressional action may be required to transfer control of National Forest lands to DOE.

5. There is a potential for flooding in the area of the dome and a need for stream diversion during the construction of the repository.

The fourth step requires that DOE evaluate each preferred site within a geohydrologic setting and decide whether such site is suitable for the development of a repository under the qualifying condition of each applicable guideline. From the evaluation, DOE concluded the following (1) the evidence does not support a finding that any of the five preferred sites are disqualified and (2) the evidence does not support a finding that any of the five preferred sites are not likely to meet all the qualifying conditions under the guidelines that do not require site characterization.

The fifth step stipulates that DOE must evaluate each preferred site within a geohydrologic setting and decide whether each site is suitable for site characterization under the qualifying conditions of each applicable guideline. In so doing, DOE concluded that all of the preferred sites are suitable for characterization.

**Table H.1. Nine potentially acceptable sites contained within five distinct geohydrologic settings**[a]

| Geohydrologic Setting | Site |
|---|---|
| Columbia Plateau | Reference Repository Location, Hanford Site, Washington |
| Great Basin | Yucca Mountain Site, Nevada |
| Permian Basin | Deaf Smith County Site and Swisher County Site, Texas |
| Paradox Basin | Lavender Canyon Site and Davis Canyon Site, Utah |
| Gulf Coastal Plain | Vacherie Dome Site, Louisiana; Cypress Creek Dome Site and Richton Dome Site, Mississippi |

[a]Defined by a USGS geohydrologic classification.

With the above findings DOE decided to nominate the RRL, Hanford Site, Washington; YM; Deaf Smith County, Texas; Davis Canyon, Utah; and Richton Dome, Mississippi. Preparation of final EAs for only these five sites reflects that decision.

## H.2 REFERENCES

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# APPENDIX I.
# THE HANFORD SITE—HANFORD, WASHINGTON

## I.1 INTRODUCTION

Site screening at the Hanford Site differs somewhat from that at the YM (which was selected by investigations begun on the NTS even though the selected site lies in part on non-NTS lands to the southwest) or the salt sites considered for the first highlevel radioactive waste repository. Like NTS, but unlike the salt sites, land use was invoked at the beginning of the site-selection process, and work progressed from the area survey narrowing to locations. In contrast to NTS, where a number of different rock types were considered, the area surrounding the Hanford Site contained only basalt. Further, the field studies, including drilling of boreholes, hydrologic testing, field mapping, geochemical analyses, geophysical survey, etc., associated with area and location surveys, were farther along than work at NTS or the salt sites.

The three major considerations addressed in the site selection process for the Hanford Site include the land-use criterion, the process by which the candidate site was identified within the Hanford Site, and the need for diversity in rock type and geologic setting among the sites to be recommended for site characterization. Because of the limited variation in rock type and geohydrologic settings, selection of the candidate location (RRL) within the Hanford Site, while thoroughly documented, appears to have raised limited discussion on the federal, state, or local level. The major interest in the site-screening process at the Hanford Site, particularly at the state level, is directed toward the land-use criterion and the need for diversity. These considerations, as applied to the sites considered for the first repository, are relatively straightforward and explicitly stated in the NWPA, and various DOE documents such as the General Siting Guidelines (10 CFR Part 960) (DOE, 1984). Even though much of the discussion mentions land use and diversity, it is directed primarily at site suitability.

This appendix follows the site-selection process at the Hanford Site from its beginnings in the 1960s through the recommendation for site characterization in 1986, but also includes the cancellation of the project in December 1987. The information is divided into three parts. The initial section on general siting work considers the early work performed at the Hanford Site. The section on identification of the candidate site reviews the selection of the RRL and reference horizon. The final section considers the nomination and selection of the RRL of the Hanford Site and the last activities there.

## I.2 GENERAL SITING WORK

The Hanford Site (originally termed Hanford Reservation in the earlier literature) is a federally owned 570 mile$^2$ tract of land located near Richland, Washington. It was selected by the U.S. Army Corps of Engineers as a site for the production of nuclear materials for defense purposes in 1942, and since that time, it has been a major facility of DOE nuclear activities.

The Hanford Site is geologically located within the Pasco Basin, a major structural feature that is part of the Yakima Fold Belt of the Columbia Plateau. Several fold structures trend northwest-southeast across the Pasco Basin; the most notable is the Cold Creek Syncline which passes through the RRL.

Consideration and study of geologic disposal of radioactive waste within the basaltic bedrock beneath the Hanford Site began in 1968 when the AEC initiated a study of the Columbia River basalts in order to develop a credible model of the structure and stratigraphy underlying the Hanford Site. This effort was directed at assessing the feasibility of providing final geologic disposal for radioactive defense waste in caverns constructed at depth within the basalts and was performed by the Atlantic Richfield Hanford Company (ARHCO) through 1972. These early studies assumed that the storage facility would be located at the Hanford Site; it appears that sites in other parts of the Columbia Plateau were not specifically reviewed. Considerations for the location of the storage facility within the Hanford Site included the proximity to existing tanks of radioactive waste and geologic factors, such as the existence of a suitably thick basalt flow at appropriate depths. Because suitable basalt flows were present under most of the Hanford Site, proximity to existing storage facilities became the significant siting criterion.

In May 1976, the newly formed NWTS Program requested ARHCO to review the earlier work and to perform a feasibility study (Atlantic Richfield Hanford Company, 1976) of using basalt as a repository host at the Hanford Site. Specific criteria directed at the siting of a repository had, however, not been formulated at this time. A number of criteria addressing isolation of radioactive waste in bedrock were generally applicable to the question of siting at Hanford (National Academy of Sciences, 1972; Piper, 1975). They included:

1. The methodology must be capable of protecting the biosphere from waste for not less than 1,000 years.

2. The excavated caverns must remain stable as long as access to the waste may be necessary.

3. The waste must not reach the biosphere in concentrations greater than the permissible maximum limits for drinking water.

4. Waste constituents may not migrate beyond a prededicated zone of contamination within the basalt so long as these constituents exceed permissible concentrations.

These criteria can be interpreted to imply that the repository at the Hanford Site should be located in a thick, low-conductivity, low-porosity basalt flow that possesses geochemical characteristics consistent with retardation of radionuclide migration. Further, this basalt flow should possess appropriate rock mechanic characteristics and be located in a stress field that is consistent with keeping the repository open for 50 to 100 years. Finally, the flow should be located in a low-gradient hydrologic regime.

The studies performed by ARHCO included geologic studies to characterize the basalts and understand stratigraphic relations, preliminary hydrologic tests to assess properties of various flows and interbeds, geochemical studies to assess compatibility between the waste and the host basaltic rock, tectonic studies to assess the stability of the Hanford region, and thermal analyses to assess the effects of heat resulting from emplacement of radioactive waste.

On September 15 and 16, 1976, a program review committee, consisting of representatives of DOE, NRC, EPA, USGS, and others met in Richland, Washington. The committee, though not addressing particular site locations, summarized its general conclusion for the Hanford Site as follows (DOE, 1980*b*):

> ... is that certain stratigraphic units of basalt rock do possess chemical and physical properties which make them strong candidates among earth materials presently being considered as suitable for long-term storage of atomic waste.

Because the Hanford Site was owned and controlled by the federal government and presumably because other sites in the Columbia Plateau were not being considered, only limited consultation with the State of Washington regarding preliminary geologic studies related to radioactive waste disposal was undertaken. Information regarding the studies was exchanged, and communication was maintained between state agencies and the Richland DOE Office. For example, distribution of an early feasibility report (Atlantic Richfield Hanford Company, 1976) included the State of Washington Department of Ecology, as well as the Washington Public Power Supply System, and various universities and colleges in the state. The ARHCO report also acknowledges cooperation from Washington academic institutions and the USGS (most likely the USGS office at Tacoma, Washington).

In September 1977, the NWTS Program allocated additional funds to support investigation of the Hanford Site and NTS as DOE controlled lands. The Hanford Program soon became the responsibility of the DOE Richland Operations Office, whereas RHO replaced ARHCO as the prime contractor responsible for this work.

BWIP was formed within RHO and was given the responsibility for site investigation, which included site-screening activities, and was organized along the lines of systems integration, geology, hydrology, engineered barrier studies, engineering testing, and the near-surface test facility (Deju, 1979).

## I.3 IDENTIFICATION OF THE REFERENCE REPOSITORY LOCATION

Site screening at the Hanford Site was initiated during 1977–1978. Because this predated the siting criteria developed by the NWTS program and the general siting guidelines mandated by the NWPA some differences in criteria and terminology were created. Because the study of the basalt and tuff sites was initiated by the DOE on the basis of land usage (in particular, federal lands where radioactive materials were already present), the screening process at the Hanford Site did not follow all of the steps discussed in the DOE guidelines that were published in 1984.

### I.3.1 Land Use

Land use was recognized in 1977 when the waste-disposal program was expanded to consider this as an alternative basis for site screening. The Hanford Site, as a federally owned tract committed to nuclear-related activities for nearly four decades, clearly met this consideration. The land-use approach also considered the advantages of locating a repository on land where radioactive waste was already stored. In addition, the land had been withdrawn from public access and committed to long-term institutional control. The land use approach was officially recommended by the General Accounting Office in 1979 and is discussed in DOE's "Statement of Position" (DOE, 1980*b*).

Although land use played a very significant role in the selection of the Hanford Site, it must be considered in conjunction with the technical merits of a site. A number of concerns have been expressed about the Hanford Site that are not necessarily directly tied to the consideration of land use in the siting process, but rather to the overall suitability of the site for characterization. A review of the hydrologic setting stated in June 1980 that the only solid justification for studying the Hanford Site is the sociopolitical fact that the land is a U.S. nuclear reservation. The report further states that, from the standpoint of hydrogeology, the Columbia River basalt group as a whole may not be well suited as a host rock for a high-level waste repository (Hydrology Overview Committee, 1980). The National Academy of Sciences (1983) acknowledged that a major reason for considering basalt was its abundance on federal lands at the Hanford Site (reservation) and the Idaho National Engineering Laboratory in Idaho. Although land use could have been invoked at the Idaho and the Savannah River facilities, these sites were found to be unsuitable for characterization on technical grounds (DOE,1980*a*).

In 1980, the state of Wisconsin (Deese,1980) suggested that DOE's activities in the basalt at the Hanford Site were inconsistent with a physical-science program that was supposed to screen areas systematically; the contention was that the BWIP siting effort was not in conformance with the Presidential Statement of February 12, 1980, (Carter, J. E., 1980). On January 31, 1984, the Yakima Indian Nation stated its disagreement with DOE's position that a valid basis for selecting sites for repositories is to begin with lands owned by the DOE and dedicated to nuclear activities. It states that federal ownership is unrelated to the geologic isolation capabilities, which is the primary criterion for site selection, and that the consideration of the Hanford Site for the first repository is entirely a matter of expediency unrelated to the characteristics of the site (Tousley, 1984). Later in 1984, the Nuclear Waste Board of the state of Washington, in commenting on the Draft DOE Mission Plan (Bishop, 1984) raised questions about the consideration of current land use in the identification of potentially acceptable sites for the first repository. In particular, they suggested that the Mission Plan implied that consideration of the Hanford Site and NTS was the result of a comprehensive screening process.

DOE responded to concerns regarding land use by noting in the Final Mission Plan (Vol. III) that it has been considered to be appropriate and prudent, had been subject to review, and that the application of other siting criteria and judgment of site suitability would be applied to areas identified on the basis of land use (DOE, 1985).

### I.3.2 Siting Objectives

The site screening process at the Hanford site differed significantly from that at the NTS, however, because only one rock type, basalt, was considered and because markedly different candidate site localities were not present within the Hanford Reservation. In retrospect, it can be seen that the siting process at the Hanford Site was one of differentiating among relatively similar potential candidate site localities (DOE, 1986*a*).

A certain amount of perspective into the early siting at the Hanford Site can be gained by examining the objectives of the Hanford siting process that was in turn based upon a number of bureaucratic assumptions as discussed in the final EA (DOE, 1986*a*).

1. The repository will require licensing involving the NRC, other federal agencies, and possibly state and local entities. License requirements will be written in the style of those of other nuclear facilities.

2. The design and operation of surface facilities will be governed by existing safety and environmental requirements.

3. Nominal design and performance characteristics for the repository have been established.

4. Long-term safety related characteristics of the host rock can be estimated.

5. The repository will consider relatively short-term retrievability and long-term isolation.

6. The site study will be based on available data and screening guidelines based on currently available technology.

A set of objectives for the Hanford siting guidelines was developed on the basis of a proposed general statement of policy for repository licensing requirements (NRC, 1978). The intent of the objectives was to identify desirable repository characteristics. These objectives include the following:

1. To minimize effects on public health and safety as related to natural hazards and hazards associated with activities of man and events and repository induced events.

2. To minimize adverse environmental and socioeconomic impacts as related to construction, operation, closure, and surveillance.

3. To minimize system costs related to construction and impact mitigation, operation and maintenance, closure, decommissioning, and surveillance.

Even though the stated siting guidelines, as contrasted to the inferred criteria discussed for the earlier time frame, do not specifically address the question of radionuclide migration, it is evident that the studies being performed at the Hanford Site put a heavy emphasis on isolation and radionuclide migration (Gephart et al. 1979). For example, a significant portion of the hydrologic studies reported on by Gephart and his coworkers dealt with hydrologic characterization and hydrologic modeling of potential radionuclide migration.

The site screening process at the Hanford site can be viewed as having seven steps (1) identification of the candidate area, (2) identification of subareas within the candidate area, (3) selection of site localities, (4) identification of candidate sites within the site localities, (5) selection of the RRL, (6) selection of the reference borehole and early shaft location, and (7) selection of the candidate horizon.

### I.3.3 Candidate Area

The area to be considered in the site-screening process was derived from expanding the Hanford Site to include all of the Pasco Basin. This area, referred to as the Pasco Basin Screening Area, included the Hanford Site and significant areas to the east and west of the site. The reason for this expansion is stated to be the need to provide a broader scope from which to understand the processes that might affect the Hanford Site and to assess whether any obviously superior sites could be found in the region outside of, but contiguous to, the Hanford Site. The expansion of the study area is in keeping with the perceived need for regional hydrologic understanding as expressed by the USGS and the Pacific Northwest Laboratory study performed under the Assessment of Effectiveness of Geologic Isolation Systems Program under the Waste Isolation Safety Assessment Program (Dove, et al. 1981). The candidate area was defined in consideration of active faults, ground motion, aircraft impact, transportation, operational radiation release, protected ecological areas, culturally important areas, and site-preparation costs.

### I.3.4 Subareas and Site Localities

Following identification of the candidate area, an overlay process employing seven exclusionary considerations (fault rupture, flooding, ground failure, erosional denudation, hazardous facilities, induced seismicity, and site-preparation costs) was used to delineate subareas. The subareas located outside the Hanford Site were eliminated on the basis of not possessing obviously superior sites to the subareas within the boundary of the Hanford site. This determination was based upon a consideration of land use, hydrology, and dip of the bedrock.

The remaining subareas were evaluated on the basis of subsurface and surface considerations, with the former being given greater weight. Five potential site localities, all located within the Hanford Site and ranging in size from approximately 10 to 50 mile$^2$ were selected. The site screening up to this point had been performed by a subcontracting firm for RHO (Woodward-Clyde Consultants, 1980).

The work during this time period was heavily concentrated inside the Hanford Site. In particular, the vast majority of boreholes and the hydrologic modeling effort were centered there. Off-site activities appear to be largely confined to data gathering, primarily directed at development of a large-scale Pasco Basin hydrologic model to be used in estimating boundary conditions for a smaller Hanford site or Cold Creek Syncline model.

### I.3.5 Candidate Sites

Following identification of the five potential site localities, candidate sites of approximately 10 square miles were identified within the site localities. A relatively complex overlaying process considering 23 parameters based upon the NRC Draft Repository Criteria (1983). ONWI Draft Site Qualification Criteria (Department of Energy, 1980*c*) NAS Guidelines (National Academy of Sciences, 1978), and reactor siting criteria (Nuclear Regulatory Commission, 1975) were used to identify nine candidate sites within the site localities. Seven of the nine sites were located within the site localities. Seven of the nine sites were located within the Cold Creek Syncline, a major structural feature of the Pasco Basin where structural deformation and hydraulic gradients appeared to be low. The two sites outside the Cold Creek Syncline were not shown to be technically superior to those within this feature, were more distant from transportation, safety, and other support facilities, and were closer to the Columbia River. They were accordingly dropped from further consideration.

Because the seven remaining sites appeared to be closely matched and were contiguous sites, a more detailed study of the area was performed (Myers and Price, 1981). On the basis of this work and other considerations, the seven sites were expanded to ten sites by the development of three additional sites generally coincident with the original ones. This scheme was deemed to better consider perceived geologic structure that showed as linear trends based upon geophysical studies.

Preliminary evaluation of these ten candidate sites indicated that they were closely matched, an elaborate evaluation process involving a criteria matrix was developed. It applied the following considerations: (1) bedrock fractures and faults, (2) lineaments, (3) potential earthquake sources, (4) groundwater travel times, (5) contaminated soil and/or groundwater that is incompatible with surface facilities; (6) thickness of the dense interior in the host flow, (7) tiering within the host flow; (8) natural vegetative communities, (9) unique microhabitats, and (10) special species. This evaluation was carried out by a siting committee formed by RHO and consisting of technical representatives from it and Woodward-Clyde Consultants.

The results of ordinal dominance analysis indicated that two candidate sites, which were almost coincident in area and location, were superior to the remaining eight sites. These sites were combined and adopted as the RRL.

As noted in the final EA (DOE, 1986*a*), the Umtanum Flow was assumed to be the reference horizon in the candidate site screening study. Also, the substitution of a thick flow in the Grande Ronde Formation for the Umtanum Flow as the reference horizon would not be expected to alter the result of this screening (see Sect. I.3.7 herein).

### I.3.6 Location of Principal Borehole and Early Shaft

Following identification of the RRL, a screening process was used to locate a principal borehole for the exploratory shaft. Six shallow boreholes, designated RRL-1 through RRL-6, were drilled in 1981 to assess the overall dip of the basalt units across this location. The overall dip was indicated to be less than one degree, and thus not a factor in locating the shaft. An overlay screening that considered land use, surface contamination, groundwater contamination, and orientation of the exploratory shaft was used next to site the shaft at a location west of the Hanford 200 West area. The RRL-2 borehole at this location was deepened from 520 to 1,175 m as of June, 1982 (Rockwell Hanford Operations, 1983).

### I.3.7 Candidate Horizon

As previously acknowledged, the Final EA (DOE, 1986*a*) acknowledges that the initial phase of the BWIP focused on the Umtanum Flow as the reference horizon. It further states that as work advanced on the engineering design for the exploratory shaft, more rigorous analyses were required to formally identify the reference repository horizon. The four-step methodology, including (1) structuring of the analysis, (2) describing the consequences for each alternative candidate horizon, (3) assessing the preferences, and (4) ranking the alternate candidate horizons is described in considerable detail in the EA. Initial screening criteria included exclusion of sedimentary interbeds and sediments overlying the basalt, flows with dense interiors less than 24 m thick, and flows above the deepest aquifer within 6 miles of the RRL. Further application of professional judgment related to hydraulic conductivity and confidence in stratigraphic correlation and continuity resulted in four candidate horizons: (1) Rocky Coulee Flow, (2) Cohassett Flow, (3) McCoy Canyon Flow, and (4) Umtanum Flow. Technical data for these candidate horizons were compiled from available data as of mid-1983.

The available data indicated differences among the four candidate horizons relating to the depth below ground surface, thickness of the dense interior, character and predictability of internal structure, zones of relatively high hydraulic conductivity, and vertical distance from overlying zones of relatively high hydraulic conductivity within the Wanupum Formation.

To aid in differentiating between the four candidate horizons, a preliminary performance assessment study was conducted. Factors considered in this assessment included consideration of the cumulative activity $^{129}I$ crossing a vertical boundary at 1 mile from the edge of the repository over 10,000 years; preclosure groundwater travel times to the 10 km vertical boundary from the edge of the proposed repository; and location of the maximum permissible concentration of $^{129}I$ in the dispersal plume at 10,000 years with respect to the base of the Priest Rapids flow. The estimates prepared in conjunction with this study were suitable for comparison purposes only and were not intended as absolute predictions.

Even though not specifically stated, it was found that (with the exception of the position of the maximum permissible concentration of $^{129}I$) the Cohassett Flow appeared to be significantly better than the other three candidate horizons. The Cohassett Flow came in second on the location of the position of maximum permissible concentration and differs from the best horizon, the Rocky Coulee, by less than 20%.

Application of the decision analysis methodology included, in addition to these performance-related factors, construction factors (such as mean and minimum thicknesses of the dense interior, and mean percentage of the dense interior exhibiting vesiculation) and cost related factors. The EA states that analyses, incorporating probabilistic and probability distributions and quantitative evaluation of uncertainties indicated that none of the candidate horizons were obviously superior for all ranking measures. For this reason, trade-offs between the ranking measures were developed by a multidisciplinary study team in structured group meetings with decision analysts from Woodward-Clyde Consultants. Based upon these trade-offs, it was determined that the Cohassett Flow ranked the highest of the four candidate horizons under both deterministic and probabilistic cases, with a significant difference in rankings under the probabilistic case. The probabilistic ranking was deemed to best represent the comparison of the horizons, and the Cohassett Flow was considered to the be preferred candidate horizon.

During this time members of the DOE Richland Operations Office BWIP Project Overview Committee (Bartlett, 1983) assessed the candidate horizons on the basis of the available technical data. In summary, findings of the committee identified the Cohassett Flow as the preferred candidate horizon. Results obtained were corroborated by using the decision-analysis approach.

From a historical perspective, reports prior to 1982 appeared to assume that the Umtanum Flow would be selected as the reference candidate horizon (≈150 ft). This flow has been found to be relatively thick throughout the Hanford Site. The major considerations for the Umtanum were the relatively great depth and potentially high temperature at the RRL. Drilling of RL-2, which was completed in June, 1982, showed that the interior of the Umtanum was only 84 ft thick at the RRL (Rockwell Hanford Operations, 1983). This was 4 ft thicker than the design-basis minimum thickness of 80 ft stated in RHO in 1983. During the late 1982–83 time period, studies for the design of the early shaft test facility considered three candidate horizons: the Cohassett (previously Middle Sentinel Bluffs), the McCoy Canyon, and the Umtanum. Some of this work is documented in early Lawrence Berkeley Laboratory letter reports. In these letter reports and in the RHO report of 1983, it is noted that the interior of the Cohassett flow is more than twice as thick as the interiors of the McCoy Canyon or Umtanum flows.

### I.3.8 Nomination and Recommendation

On February 2, 1983, the U.S. Secretary of Energy officially notified the State of Washington, in accordance with the NWPA, that the RRL at the Hanford Site had been selected as the potentially acceptable site for a nuclear waste repository. This predated the development of the DOE General Siting Guidelines which were published in the Federal Register in December, 1984. The first draft of the guidelines was issued in February, 1983. Following public hearings and consultation with the affected states and key Federal agencies, the proposed guidelines were reviewed by the NRC and approved by unanimous vote at a public meeting in June 1984. The guidelines were issued in final form in November 1984 and became effective on January 7, 1985.

Following the development of the of the guidelines, DOE issued a draft EA for the Hanford Site in December, 1984. Prior to the issuance of the draft EA, public hearings were held in the state of Washington in March 1983 in accordance with the 1982 Act to receive recommendations on issues that should be addressed in the EA and any Site Characterization Plan for the Hanford Site. The draft EA for the Hanford Site provided extensive background information on the site and evaluated the site in terms of DOE General Siting Guidelines. In the common Chapter 7 of the nine draft EAs, the Hanford Site is identified as one of the five sites to be proposed for nomination and is shown to be in the top ranks of any of the three types of overall rankings of sites discussed in the draft EA.

DOE provided a 90-d comment period following issuance of the draft EA on December 20, 1984. During this period, public hearings on the draft EA for the Hanford Site were held at the following locations (1) Federal Building, Richland, Washington, on March 5, 1985; (2) Department of Social and Health Services Office Building, Olympia, Washington, on March 7, 1985; (3) Federal Building, Seattle, Washington, on March 9, 1985; and (4) Battelle Pacific Auditorium, Portland, Oregon, on March 11, 1985. The moderator of these hearings was not an employee of DOE. A summary of the process by which the Hanford Site was selected as being a potentially acceptable site was presented, and public statements on the selection process and the draft EA for the Hanford Site were accepted.

Following the consideration of comments received on the draft EA from the public, the states, the NRC, and other Federal agencies, the Secretary nominated the Hanford Site as one of the five sites suitable for site characterization and requested that the final EA for the Hanford Site be published.

Following nomination, DOE subjected Hanford and the other four nominated sites to a ranking process to arrive at the three sites to be recommended by the Secretary to the President for approval for site characterization. In response to comments and concerns regarding the ranking methodology discussed in Chapter 7 of the draft EAs, the DOE adopted a more formal decision and ranking analysis. This analysis developed largely on the basis of comments by the National Academy of Sciences and is described in DOE (Department of Energy, 1986*b*). The methodology applied to the five sites is based on a multiattribute utility analysis and is a decision-aiding methodology that is a refinement of one of several methods proposed in the draft EAs in 1984. DOE notes that, as in the case of most formal methods, the decision-aiding methodology can provide only a partial and approximate accounting of the factors related to the site recommendation decision. It does not apply the diversity guidelines called for in the 1982 Act and required in the determination of the final order of preference among the sites. This latter point is of particular importance to the Hanford Site, which is the sole representative of one of the geologic media found among the five sites. In applying the decision-aiding methodology to the five nominated sites, DOE identified two postclosure objectives related to the isolation of waste from the accessible environment and prevention of adverse effects to public health and safety after repository closure. It further identified four preclosure objectives related to (1) minimizing adverse impacts on public health and safety before closure, (2) minimizing environmental impacts, (3) minimizing socioeconomic impacts, and (4) minimizing economic costs. In keeping with the DOE General Siting Guidelines, greater emphasis is placed on the postclosure considerations.

Application of the postclosure analyses to the five sites indicated that the base case stipulated, " ... all of the sites are expected to perform extremely well and are capable of providing exceptionally good waste isolation for at least 100,000 years after repository closure" (Department of Energy, 1986*b*). Postclosure performance of a repository at the Hanford Site, however, would be less favorable than a repository at the salt sites or the Nevada Site. The ranking of the Hanford Site from the preclosure analysis is very sensitive to differences in costs, especially repository costs. If only health and safety impacts and environmental and socioeconomic impacts are considered, the Hanford Site is ranked above the remaining four sites. If costs are considered, the Hanford Site ranks fifth behind the other four sites. The overall ranking of the sites based on a composite analysis of postclosure and preclosure analysis is the Nevada Site, the Richton Dome Site, the Deaf Smith Site, the Davis Canyon Site, and the Hanford Site. As discussed in the recommendation report by the Secretary, this ranking " ... is most strongly influenced by the estimated repository and transportation costs (factors that are the least important to all guideline subgroups in the siting guidelines" (Department of Energy, 1986*c*). The postclosure evaluation is shown to have limited use as a discriminator but provides evidence that all of the five sites exhibit attractive postclosure performance.

### I.3.9 Diversity of Geologic Settings

The remaining consideration in the selection of sites to be recommended for site characterization is diversity in both geohydrologic settings and rock types. The Act of 1982 requires that the Secretary "consider the various geologic media in which sites for repositories may be located and, to the extent practicable, recommend sites in different geologic media." DOE Siting Guidelines state that to the extend possible, candidate sites recommended for site characterization shall have different types of host rock. The rationale for the diversity consideration has been stated by DOE as a means of avoiding the possibility of site characterizations at three sites in similar media, demonstrating nonacceptability of all sites. However, concerns regarding emphasis on diversity to include the Hanford Site in the three sites to be recommended were raised by the state of Washington (Bishop 1984), the state of Wisconsin (Deese, 1980), the Yakima Indian Nation (Tousley, 1984), and others.

On the basis of the information presented in the final EAs, the application of the decision-making methodology and consideration of the uncertainty and timing of costs, the Secretary recommended " ...an initial order of preference in which the YM; Deaf Smith County, Texas; and Hanford, Washington sites are the three preferred sites for site characterization." The Secretary added, "This order to preference provides the maximum diversity of geohydrologic settings and rock types" (Department of Energy, 1986g).

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# APPENDIX J.
# THE YUCCA MOUNTAIN SITE, NEVADA, AND THE NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS

## J.1 PRE-NWPA ACTIVITIES

### J.1.1 Period 1976

Prior to the establishment of OWI in February 1976 and before any concerted interest in the NTS for purposes of HLW disposal, the USGS (was engaged in various geologic studies and field mapping in both the southern Basin and Range Province and at the NTS proper (Carr and Quinlivan, 1966) (Blankennagel and Weir, 1973; Carr, 1974; Winograd and Thordarson, 1975). It is therefore not surprising that the initial siting investigations at the NTS, begun during the early OWI/NWTS program, were undertaken by the USGS.

#### J.1.1.1 Criteria

Initially, the principal interest at the NTS was directed at the waste-disposal potential of a clay-rich unit called the Eleana Formation (Hoover, 1976). In particular, attention was focused on a more plastic, extremely clay-rich zone designated at Unit J.

#### J.1.1.2 Consultation and coordination

Since the NTS represents a sizable tract of land owned and access-controlled by the federal government, consultation with the state of Nevada about preliminary geologic studies related to waste disposal was not undertaken in the usually accepted sense of this term. Normal avenues for information exchange and discussions were, however, maintained between the state through the Energy Research and Development Administration/Nevada Operations Office in Las Vegas, Nevada.

#### J.1.1.3 Technical issues

In terms of the initial evaluation of the NTS and the Eleana Formation, the following geotechnical issues were considered important (1) finding structural blocks that contained adequate thickness of the formation, and in particular, the more promising Unit J, (2) determining the tectonic stability of those Unit J-bearing structural blocks in terms of local faulting and intrusive-hydrothermal activity; and (3) establishing the presence of argillite-rich intervals within the trends determined from (1) and (2) above. The proximity of any structural block to areas where underground weapons testing would be conducted represented another technical issue important to the screening of potential study sites. On the basis of these issues, only one structural block, Syncline Ridge in the Southern Eleana Range, was determined to be a potentially favorable from the total of five sites (Quartzite Ridge-Argillite , North Eleana Ridge, Mine Mountain, and Calico Hills are the other four) originally investigated.

#### J.1.1.4 Programmatic organizations

OWI had been established as a separate entity within the Nuclear Division of the Union Carbide Corporation and coordinated the NWTS program through the Oak Ridge, Tennessee Operations Office. The geologic program at the NTS, while integrated into the OWI/NWTS program through information exchanges and technical meetings was, however, under the management of ERDA/NVO.

From its inception, OWI established a six-member GRG whose responsibility among other objectives was "to study and critically review all geology study plans and activities of the NWTS program leading to site selection." At the March 1977 GRG meeting, a detailed briefing on the studies then underway at the NTS was presented by OWI staff. In the GRG summary report issued in July 1977, various recommendations supportive of additional detailed work at the NTS were presented.

Over this same span of time, the American Association of State Geologists (AASG) established an eight-member review group which principally interfaced directly with ERDA Headquarters. A joint meeting with the GRG was held in March 1977, at which time a general review of the OWI/NWTS program was held. However, the AASG Review Group did not play a direct role in the NTS project.

In early 1977, a decision was made by ERDA to greatly expand the geotechnical work at the NTS beyond merely an evaluation of the Eleana Formation. This decision was in response to the perceived need to site and construct a repository under an accelerated time table amid national security concerns over waste disposal. The fact that NTS lands were already dedicated to nuclear-based activities undoubtedly influenced this decision at that time. Also contributing to it was the opinion expressed by the USGS that the NTS represented a potentially promising tract to investigate for a repository (Dudley 1977). In particular, the USGS cited several general attributes to support their view, which were (1) a diverse geology that contained several rock types with waste isolation promise; (2) a deep water table and long flow paths for the groundwater systems; (3) an arid climate and physiography that collectively were responsible for item as well as a low volume of moving groundwater given the small amount of recharge; and (4) drainage into closed hydrologic basins.

Although OWI remained actively involved in both technical and coordination matters at the NTS following this decision, a codecision had been made to entrust more of the program's direction to a working group whose constituent organizations were located closer to the NTS. Thus, greater technical involvement was realized by: (1) SNL, (2) LASL, (3)LBNL, and (4) LLNL. The USGS remained the principal geotechnical participant. Some of this enlarged multiorganization participation was due to the enlarged scope of the exploration effort at the NTS wherein granitic rock bodies initially would join the Eleana Formation as potential host media under evaluation. Some of it was furthermore due to the planned undertaking of in situ tests in both the Eleana argillite and granitic pluton (Climax stock). Local management/administrative control was also increased over this same time with ERDA/NVO assuming a larger role.

Therefore, from a historical perspective, May 1977 can be considered the starting point for what has since become known as the Nevada Nuclear Waste Storage Investigations Project. As a result of the expanded program and the revised organizational makeup, changes obviously occur at this point for three work elements, namely criteria, technical issues, and programmatic organization issue were: (1) better data base and level of knowledge about the location of faults, including any potentially active ones; (2) recurrence intervals of fault movement, especially along large faults; and (3) the likelihood of recurrent volcanism. Any changes in the hydrologic regime, especially caused by altered erosional rates due to either future climatic changes, recurrent volcanism, or reactivated faulting, were also of considerable interest.

Another important technical issue for the entire NTS and the adjacent region was seismicity, a process directly related to tectonic setting and fault systems. Induced seismicity caused by nuclear detonations represented a unique subissue.

### J.1.1.5 Programmatic organization

Major responsibility for the geologic, geochemical, and hydrologic studies at the NTS continued to rest with the USGS. Technical discussion and coordination between the USGS, OWI, and the several laboratory organizations remained active, especially in regard to planning the overall exploration program and in situ tests. LLNL assumed the lead role with regard to the Climax granitic stock, while Sandia National Laboratories did likewise with the Eleana argillite.

### J.1.1.6 In situ tests

The objectives of the in situ thermal test in the Eleana argillite were (1) to determine the effects of heating on this potential host rock and (2) to compare the field results with data generated by models in order to confirm the predictive capability of the latter (McVey et al. 1979; 1980; Lappin and Olsson 1980). In summary, this in situ test revealed (1) reasonably good agreement, with minor departures, between the predicted and observed temperature fields; (2) clay contraction, caused by the increased temperatures, resulted in the enlargement of existing fractures, with greater movement of fluids, including steam, through them; and (3) dehydration of the clays caused decreased thermal conductivity of the rock mass. It thus became clear that heating caused significant changes to the physical properties of this rock. Adjustment of the models so that future versions could consider fractures and variable thermal conductivities was mandated in order to improve their predictive capacity.

In the case of the Climax granite, a more technically complicated in situ test had been designed. Several differences in comparison with the Eleana test were (1) preliminary thermal data were obtained in the field before emplacement of the full-scale test array; (2) actual spent nuclear fuel in canisters was used, as well as electrical heaters; thus, both thermal and radiation effects were involved; (3) the test facility is 1,378 ft below the land surface; and (4) some rock-mechanical measurements were also taken during mining construction of the tunnel complex where the test was located. This test also was designed with more objectives in mind, namely: (1) to determine the effects on granodiorite-quartz monozonite (granitic rock) caused by spent fuel; (2) to compare and evaluate any differences in the thermal load produced by waste heat versus that from simulated heaters; (3) to compare rock-mechanical responses due to mining versus thermal loading; (4) to compare actual heat removed by means of mine ventilation versus that predicted by model studies; and (5) to contrast the thermomechanical response of rock masses with different levels of fracture density. Beyond the geotechnical value of this in situ test, considerable operational experience was also obtained in terms of waste encapsulation, waste handling and emplacement, and retrieval design.

### J.1.3 Period 1978–1979

In mid-1978, OWI was discontinued at the request of its founding corporation; responsibility for managing the NWTS program on lands not controlled by DOE was transferred at that time to the ONWI. Under this revision, ONWI became responsible for technology development in waste disposal and for program coordination within the NWTS.

Characterization of sites on non-DOE lands was principally aimed at those underlain by rock salt, although lesser-scale studies on other rock types were also conducted under ONWI direction. The ONWI and Hanford basalt (BWIP) programs were both administered by the DOE Richland Operations Office, which, in turn, established a program office at Columbus, Ohio.

The NNWSI program continued to be administered by the NVO of DOE, with continued technical involvement from SNL, LLNL, LASL, and the USGS (Denver). Coordination over all three NWTS programs was provided by the Office of Waste Isolation located at DOE headquarters. Continued exchange of information about the NNWSI was afforded by the inclusion of various papers given at the annual NWTS information meetings that were sponsored and directed by ONWI, although technical publications still were issued by the two principal investigating organizations (USGS and SNL).

#### J.1.3.1 Criteria

In addition to his indefinite postponement on the reprocessing of spent fuel the previous year, President Carter in 1978 created an Interagency Review Group to study and make recommendations about the multifaceted problem of nuclear waste management in the country. One of the principal contributions from that panel was the recommendation to increase the level of study and associated body of knowledge about several nonsalt host rocks (Interagency Review Group on Nuclear Waste Management 1979). This view came at a time in which the original NTS studies had expanded from a single focus (namely, the Eleana

Formation and the argillites within it) to a broader consideration of sites on the NTS that entailed granitic bedrock, volcanic tuff, and intermontane alluvium fill, in addition to argillite. Beyond the site-specific interest development in these four potential host media, argillite and granite also underwent significant in situ tests thereby essential generic properties could be studied. Alluvium was soon dropped from the list because of it very low thermal conductivity (Smyth et al., 1979).

However, two problems at the NTS continued to vex the NNWSI program. The first involved tectonic stability and associated complex geologic structures. A reasonable body of thinking had developed the view that detained site characterization, especially in light of new tectonic stability criteria being formulated for the NWTS program, would lead to the rejection of most, if not all, of the sites considered to date. In fact, geologic investigations, including exploratory drilling, had revealed by early 1978 that the structural geology of the Eleana Formation (argillite) at Syncline Ridge was very complex. The published USGS reports on this subject carry later dates (Hoover and Morrison, 1980; Ponce and Hanna, 1982). Because of this complexity, it was felt that full-scale site characterization would result in a tenuous formal license application (Stephens, 1978). Therefore, in early August, it was recommended that the Syncline Ridge site be dropped from further consideration (Cotter, 1978).

At approximately the same time, a DOE task force had arrived at the conclusion that only the southwestern part of the NTS would be suitable for a repository, given perceived conflicts with weapons-testing mission elsewhere on the facility. By early August 1978, the Acting Assistant Secretary for Defense Programs formally embodied the task force's findings and ruled that all sites considered thus far were unacceptable for a repository because they were too close to weapons testing and might hamper the tests. On that basis, the Timber Mountain, Climax, and Twin Ridge sites were dropped from further consideration. Syncline Ridge was among the sites excluded by this decision, although its complex geology had already made that assignment academic.

As a further resolution of the weapons-testing issue, it was agreed that subsequent repository siting investigations would be conducted only within an area ≈ 16 mile$^2$ in the extreme southwestern corner of the NTS, this portion later became known as the NRDA. Adjacent off-site areas that bounded this sector could also be studied and included lands under the control of the United States, the Nellis Air Force range to the west, and lands under the control of the U.S. Bureau of Land Management to the west and south.

Immediately after the weapons-testing ruling, the USGS helped to compile a list of five potential areas for further study within or near the NRDA. Two of these, namely Jackass Flats and Skull Mountain, were soon removed from consideration, leaving Calico Hills, Wahmonie, and YM.

A geophysical (aeromagnetic) survey of the Calico Hills area had been interpreted initially to indicate the presence of a granitic intrusive some 1,600 ft beneath the land surface. In 1978, the first exploratory borehole drilled within the NRDA attempted to confirm that granite was under the Calico Hills. At a depth of 2,350 ft drilling was discontinued without encountering granite (Maldonado et al., 1979). A thick section of the Eleana Formation which contained a thermally metamorphosed magnetite-rich interval of argillite was eventually proven to have caused the aeromagnetic anomaly. A subsequent gravity survey could not establish the presence of any granitic intrusive (Snyder and Oliver, 1981). Other geophysical surveys indicated that the Eleana Formation argillites were as structurally complex in this area as those at Syncline Ridge (Hoover et al., 1982). Because no granite could be found and the argillites were badly deformed, the Calico Hills site was dropped from further consideration in early 1979 (Twenhofel, 1979).

During this period, granite at the Wahmonie site was also studied by means of surface mapping and geophysical surveys, which revealed that the rock was highly fractured, hydrothermally altered, and associated with faults along which modern displacement may have occurred (Smith et al., 1981; Hoover et al., 1982). Because of these features and the potentially small subsurface extent of the granitic rock body, the Wahmonie site was abandoned in April 1979 (Twenhofel, 1979).

At YM an exploratory borehole drilled to 2,500 ft in late 1978 encountered a thick sequence of volcanic tuffs, some of which were rich in zeolite (Spengler, et al., 1979). Previous USGS geologic mapping (Christiansen and Lipman, 1965; Lipman and McKay 1965) had revealed the presence of relatively undisturbed areas of fairly sizable extent. With the demise of the two granite sites (Calico Hills and Wahmonie), the USGS recommended that further exploration be concentrated at Yucca Mountain even though the potential host rock (i.e., volcanic tuff) was not well characterized at that time (Twenhofel, 1979). That recommendation was accepted by DOE.

In late April, May, and July 1979, three technical, peer-review groups met respectively to evaluate the NNWSI program. These panels generally supported DOE decision to focus future studies on YM and volcanic tuff.

### J.1.3.2 Disposal methods

During this time, mined geologic repositories remained the choice for the future disposal of spent fuel, commercial high-level waste, or defense high-level waste. This view was clearly upheld in both the draft and final versions of the environmental impact statements on the management of commercially generated radioactive waste (AEC, 1974; DOE, 1980*a*).

Although the Swedish KBS program would not influence the US program design considerations for a few years, it should be noted here that the important documents, known informally as KBS-I and KBS-II, were prepared and released in late 1977 and late 1978, respectively. From these documents arose the concept that multiple, engineered barriers could be combined with the rock-mass properties of the repository host rock to preclude radionuclide migration (National Academy of Sciences, 1980). Various aspects of this concept are discussed in more detail in a subsequent section (Sect. S.1.4.2).

### J.1.3.3 Consultation and cooperation (C&C)

The state of Nevada was advised of DOE's decision to eliminate certain study sites on the NTS because of the possible conflict with the weapons-testing program. The state was also apprised of the intended focus by the NNSWI Project on the NRDA and the immediately adjacent tracts on Air Force and BLM lands. It is not clear if the peer-review-supported decision to focus post-1979 studies on YM and volcanic tuff was specifically conveyed to the state at this time.

### J.1.3.4 Technical issues

As early as 1978, some uncertainty was expressed about the waste-disposal capabilities of volcanic tuff inasmuch as so few detailed studies had been undertaken (Smyth et al., 1978). In September of that year, a presentation of the results of hydrological studies involving tuff was made to the Committee on Radioactive Waste Management of the National Academy of Sciences (Lincoln and Dudley, 1978; Tyler, 1979). This meeting was designed to solicit the committee's views on the favorable and unfavorable characteristics of tuff(s) and to determine whether this category of rocks was sufficiently promising as a potential host medium to warrant further study. Although no immediate written endorsement resulted from the meeting, the committee informally supported additional study and outlined several unresolved issues that became the focus of such investigations. It was not until 7 months later that an NRC member of the committee sent written support to DOE regarding further investigation of tuff(s) (Gloyna, 1979).

### J.1.3.5 Programmatic organization

Within the NNWSI project, SNL remained the lead organization, with LASL, LLNL, and LBNL providing specialized technical input for in situ tests and planning developments relative to the future field and laboratory studies of volcanic tuff(s). The USGS continued as the principal geotechnical participant for field mapping, geophysical surveys, drilling and related borehole testing, hydrologic testing, and regional-to-local tectonic and structural geology investigations.

In mid-1979, three peer review panels were convened for single meetings to evaluate the NNWSI project and to make attendant recommendations. The panels were charged, respectively, with reviewing (1) host rock or media studies, (2) geologic and hydrologic studies, and (3) tectonic-seismic-volcanic studies. A fourth panel also reviewed the Climax granite in situ test. Each panel consisted of national experts who were knowledgeable in either waste disposal or specific geotechnical areas and other geotechnical experts who were especially familiar with the geology and local geologic setting of Nevada and the NTS.

### J.1.4 Period 1980-1982

At the outset of 1980, ONWI directed part of its program-integration effort toward the formulation of specific siting, or site qualification, criteria. The ONWI generated consideration of siting criteria also led to a similar response within the NNWSI project. The fact that the approach to the NNWSI and BWIP projects differed from that of the ONWI effort (namely site selection based on land use vs site selection based on the host-rock type) was the eventual rationale for project-specific siting criteria. Much of the NNWSI siting criteria work was undertaken by SNL (Sinnock et al., 1980; Sinnock and Fernandez, 1982).

### J.1.4.1 Criteria

As the NWTS program moved into the 1980s, four considerations emerged as important criteria in the continuing evaluation of repository sites on the NTS under NNWSI: (1) ongoing studies of the tectonic-volcanic history of the southern Great Basin and the tectonic-volcanic-seismic stability of the NTS proper; (2) an increased concentration of geologic and hydrologic studies, geophysical surveys, and borehole investigations within the tuff-bearing sequence at YM; (3) rock-mechanical, thermal-mineralogical, and mineral-stability studies on volcanic tuffs (both welded and zeolitic types); and (4) development of data bases and screening procedures so that discriminating geologic and environmental characteristics could be formulated into siting criteria compatible with those being developed by ONWI.

Three indirect activities (i.e., not fully related to the repository-siting effort), continued: (1) in situ testing of the Climax granite; (2) radionuclide-migration studies of several rock types, including volcanic tuff; and (3) demonstrations in handling encapsulation transportation of waste.

Since the mid-1979 decision to focus the repository-siting exploration effort on the YM area, the geologic studies emphasized the local stratigraphy, structure, geochemistry, volcanic history, and seismicity. Hydrologic studies were oriented toward understanding the regional groundwater flow as well as the flow of water through the unsaturated zone, given the deep water table in the area.

Specific techniques employed in these geologic studies were field mapping, geophysical surveys, exploratory drilling and downhole testing, and core analysis. Hydrologic methods focused on borehole testings and the development of flow models. Individual geophysical techniques that were used to gather indirect data at YM included seismic reflection, seismic refraction, gravity, magnetic, and electrical surveys.

During the first four years (1976–1980) of the NNWSI project, the identification and selection of areas and sites on which to center exploratory activities had been an informal process, guided by an increasing body of field and laboratory based knowledge about the local and NRDA-specific geology at the NTS. The series of decisions in late 1979 to focus study on the volcanic tuff sequence at YM were reached in a similarly informal manner.

In one sense, YM was initially selected by default. By late 1979, the two Eleana argillite-bearing sites, Syncline Ridge and Calico Hills, had been rejected basically because of structural-geologic complexities, even though the former site was also eliminated as the result of the weapons-testing agreement. The three granite-bearing sites, namely Timber Mountain, Climax Stock, and Twin Ridge, in the northern half of the NTS, had been removed from further consideration by this same weapons-related decision. The granite-bearing sites in or near the NRDA in the southwestern part of the NTS had also been discarded because (1) no granite could be found at one (Calico Hills) and (2) the local geology of the other (Wahmonie) exhibited numerous deleterious characteristics. Other previously considered sites, namely Jackass Flats and Skull Mountain, had been abandoned in late 1978, because they were the least promising of those compiled at that time. Therefore, by the beginning of 1980, the YM area was the only site in contention.

At this point, the NNWSI undertook to address site screening at the NRDA in a more formal manner and a screening process was initiated whereby it would be determined if YM was indeed the most appropriate site for additional exploration and characterization.

Because the NNWSI project at the NTS had been founded on the land-use approach involving nuclear-dedicated lands under DOE control, the point of equivalent comparison to the host-rock method was at the area-to-location stage. The NTS was a small-enough parcel of land that there was no need to consider national or regional surveys. According to the various site-screening steps that were developed for the host-rock approach and described in the National Plan, after location surveys were conducted to identify specific sites, detailed site investigations, and, eventually, site selection constituted the remaining siting activities to be performed prior to official recommendation and license application.

Development of the unique NNWSI site-screening documentation can be traced by means of several SNL publications (Sinnock et al., 1980 and 1981). In general, the recommended approach for screening consisted of (1) developing quantitative criteria in order to rate the suitability of different locations, (2) compiling all available information in terms of selected attributes based on geologic, host rock, and environmental considerations, and (3) comparing the attributes with the criteria in some formal manner.

The NWTS site-performance criteria, as published by DOE, were divided into the following ten categories: (1) site geometry, (2) geohydrology, (3) geochemistry, (4) geologic characteristics, (5) tectonic environment, (6) human intrusion, (7) surface characteristics, (8) demography, (9) environmental protection, and (10) socioeconomic impacts. Under these categories, 36 specific criteria were outlined; for example, the site geometry category contained three criteria (1) minimum depth, (2) thickness, and (3) lateral extent (referring to the dimensional aspects of the host rock at a site). NNWSI (Sinnock and Fernandez, 1981 and 1982) also formulated their criteria as a series of performance or screening objectives within a three-tiered hierarchy. The four principal (highest level of the hierarchical tree) objectives were: (1) containment, (2) isolation, (3) construction, and (4) environment. Under these highest-level objectives were 12 second-level objectives, and under those, in turn, were 38 third-level objectives. For example, under containment, one second-level objective was the selection of natural systems having minimum potential for disruptive processes that might affect the waste package; one of the third-level objectives within the sequence was to minimize the potential for volcanic disruptive processes. Tables 2-1 and 2-2 in the final EA (DOE, 1986) cross reference these three-tiered objectives to the other siting criteria extant at that time (early 1980s)–namely, those promulgated by NRC as 10 CFR Part 60. Also, these NNWSI performance objectives are correlated in Table 2–2 of the EA, with the final siting guidelines issued by DOE as 10 CFR Part 960 (DOE, 1984) in response to the NWPA. These latter guidelines, of course, did not exist when the NNWSI screening effort was being developed and applied.

Each of the objectives was then reviewed by a panel of experts and evaluated in terms of their individual importance within each level. The composite or mean importance therein provided a ranking or weighting factor that could be applied to each objective. For example, isolation was the highest ranked first-level objective, radionuclide migration (a second-level objective under isolation) was the highest ranked in the level, and groundwater flow (a third-level objective under isolation and radionuclide migration) was the second highest ranked at that level. The results of the expert panels and the resulting assignment of percentage weights based on importance were summarized in the EA (DOE, 1986).

As a second element of the screening process, a total of 31 physical attributes were compiled into two broad categories: geographical and host rock. These attributes each had to: (1) show variation throughout the area (NRDA on the NTS and adjacent lands) being screened and (2) reflect a condition capable of influencing behavior of the repository. Some geographical-based attributes are fault density, thickness of the unsaturated zone, and potential cultural resources. Thermal conductivity, mineral stability, and compressive strength illustrate host-rock attributes. It may be of interest that NNWSI compiled 23 geographical attributes, but only 8 host-rock attributes. Table 2-3 in the EA lists all the attributes. The assignment of weighting factors amid a matrix system that cross-linked these 31 attributes to the three levels of performance objectives was also discussed (Sinnock et al., 1984). In addition, favorability estimates, assigned on a relative basis of zero to ten, were also established in graphical form so that each attribute could be quantitatively compared with the objectives as arranged in the attributes/objectives matrix (Sinnock, et at., 1984).

This entire, rather elaborate screening process was digitized and entered into a computer graphics system containing some 1514 half-mile square grid cells and nine candidate host rocks. Calculations were made for each grid cell against the geographical attributes and for each host rock against the host rock attributes in the following manner: favorability value of each attribute times weight of the attribute times successive weights for each of three levels of performance objectives. The final rating for each cell was the total score of all these weighted number calculations under both categories of attributes, as scaled to a maximum of 100,000. These ratings, grouped into divisions of low, medium, and high overall favorability, were then displayed on base maps of the screening area, thus showing the range of grid cell ratings for one set of calculations (i.e., all the geographical attributes) (Sinnock and Fernandez, 1982). Another map was registered when the ratings for each containing the highest-rated host rock were superimposed on the earlier map. In this manner, the contribution, in part, for the host-rock attribute calculations could be visually displayed.

On the basis of these graphical summing operations, predicated upon 25 separate analyses, it was possible to discriminate 15 alternative locations within the screening area. To distinguish among these locations, subsets of the more important performance objectives/attributes were designated and then reviewed by the panel of experts who applied percentage weights to each of the subsets. These weighting factors were then used to quantify the 12 analyses performed on different combinations of related objectives against a set of rating categories. Five rating categories, ranging from high (where all of most of the grid cells rate high) to low (where all or most grid cells rate low) were used to reveal the number and collective weights of the 12 analyses conducted for each location. Location J, or the Northern Yucca Mountain location, which contains the Yucca Mountain site, proved to be the highest-rated location.

**J.1.4.2 Disposal methods**
By early 1980, DOE had established its position on the performance objectives for a high-level waste isolation system (geologic disposal or otherwise) by means of the Waste Confidence Rulemaking Statement in conjunction with the NRC (DOE,1980*b*; NRC, 1979). Among the major points expressed were (1) a distinction between containment and isolation, (2) the identification of 10,000 years as the minimum isolation time frame, and (3) a measure of conservatism in various design considerations. The latter largely embraced the multiple-barrier concept originated by the Swedish KBS Program for granite repositories. As discussed in the National Plan, it is clear that multiple engineered barriers incorporated into the waste package were expected to function together with the repository itself and the host rock at the selected site to accomplish both containment and isolation.

Thus, aspects such as waste form, overpack material around the waste form, high-integrity canister materials, emplacement sleeve, and backfill have become accepted as the barriers within this redundantly designed disposal system. Of greater significance, however, was that this containment/isolation concept would be applied to the final repository disposal system regardless of host rock. In other words, a concept that was devised overseas in reference to granite has been extended to apply to rock salt, volcanic tuff, and basalt within the domestic program for the first repository.

**J.1.4.3 Relationships with State, Indian Tribes, and the Public.**
In mid-1980, DOE notified by letter the governors of the seven states (Louisiana, Mississippi, New Mexico, Texas, Utah, Washington, and Nevada) where repository-site exploration efforts were already active about the expanded program as embodied in message to Congress by President Carter. No specific commentary existed in the letter to the Governor of Nevada regarding either the NTS or the NNWSI project.

By early 1982, when the National Plan was issued, DOE had formulated and was implementing a comprehensive consultation process. Within that framework, the NVO continued to apprise the state of Nevada officials about the progress being made in siting and other repository-related activities on the NTS and lands adjacent to the NRDA.

As the result of more formalized site-screening (area-to-location-phase) analysis that led to the selection of YM and the designation of suitable waste-disposal horizons (including the preferred Topapah Spring Tuff) at the Yucca Mountain site, DOE was, by late 1982, in a position to officially identify YM as a potentially acceptable site. In early February 1983, then Secretary of Energy Donald P. Hodel, sent the Governor of Nevada, Richard H. Bryan, official notification of that designation.

**J.1.4.4 Technical issues**
As the focus of interest over this time period clearly shifted to the Yucca Mountain area, several technical issues could be identified: (1) continued characterization of the thermal, rock-mechanical, mineralogical, and mineral-stability aspects of volcanic tuff, but now with direct reference to those stratigraphic units present at YM; (2) development of the data base for the selection of a preferred horizon for the construction of the anticipated exploratory shaft (ES) and possible Test and Evaluation Facility (TEF); (3) design of the various testing procedures (including in situ) that could be involved in the ES; and (4) planned preparation of various regulatory documents that would be expected, given the anticipated development under item (2) above.

The National Plan described in some detail the need and concept of a TEF. The stated DOE policy then indicated intentions for only one such facility to be constructed at one of the first three potential repository sites. In 1981, the NRC procedural regulations (10 CFR Part 60) had also advanced the concept of exploratory shafts being constructed at each proposed repository site, with testing of rock being conducted at repository depths in each shaft.

The NNWSI project was initially anxious, during the 1981—82 period, to be prepared for both an ES and TEF (Lappin, 1981: Myers and Nelson, 1982). To the extent that the stratigraphy at YM was then known, four candidate stratigraphic units had been identified as possible reference horizons. From oldest to youngest, these were the Tram and Bullfron Members of the Crater Flat Tuff, the Tuffaceous Beds of Calico Hills (an informal stratigraphic term), and the Topopah Spring Member of the Paintbrush Tuff. The former two lie below the water table, whereas the latter two are within the unsaturated zone. All but the Calico Hills are characterized by abundant welded tuff.

Preliminary data on which to base the horizon evaluation decision were to include thermal conductivity and expansion, rock-mechanical properties of the matrix (rock) and fractures, certain bulk properties, and the overall thermomechanical stratigraphy at YM (Lappin, 1981). A letter supporting the concept of a repository within the unsaturated zone was furthermore presented to DOE/NVO by the USGS in February 1982 (Robertson, 1982). On the basis of the data available in July 1982 the Topopah Spring Tuff was selected as the reference horizon. It was not until 7 months later (February 1983) that the final, complete evaluation of these four candidate rock units were finished; the results supported the earlier preliminary decision. The report that outlines these final findings was released the following year (Johnstone et al., 1984).

In a related decision, the ES was designated to be located in Coyote Washington along the eastern side of YM, and on land under Air Force control west of the NRDA. This site was selected from five candidate sites that had been chosen by a two-step screening process. However, the ranking parameters that were used, and the results of the selection process were not published until 1984 (Bertram, 1984).

### J.1.4.5 Programmatic organizations

Within the NWTS management structure, little had changed with regard to NNWSI by 1982 when the National Plan was released. The DOE/NVO continued to programmatically administer the project and reported to the Office of Waste Isolation at DOE/Headquarters. The principal subcontractor remained SNL, with the USGS continuing to provide significant geologic and hydrologic technical input as part of an existing Memorandum of Understanding between DOE and the Department of the Interior. Technical support was also continued by LASL and LLNL, much of it in the efforts to characterize the waste-disposal capabilities of volcanic tuff(s).

Two noteworthy changes did, however, take place in the programmatic direction of NNWSI, but they did not entail any major organizational changes. Beginning in late 1980, an integrated waste package program involving tuff was jointly implemented by SNL and LASL (Johnstone and Vine, 1980; Johnstone et al., 1981). In the context of the then-accepted multiple-barrier concept, a range of waste package components was to be evaluated, data from the YM tuff sequence and the G-tunnel in situ facilities were to be included in the analyses, and models designed to make long-term predictions were to be developed. Subsequently, LLNL became more fully involved in this ongoing program.

Building upon the departure from the more traditional NNWSI program, namely one of site selection and characterization, a full range of activities, including systems analysis, conceptual repository design, and full-scale waste package development, was added to the project in late 1982. Again, the three laboratory organizations (SNL, LASL, and LLNL) collaborated on the work outlined above. Beyond the need to further evaluate and model the various interactions of welded tuff was the responsibility to more fully analyze the unsaturated zone.

With the addition of these programmatic elements, the NNWSI project had become a fully integrated waste-disposal effort. Any generic concepts previously inherited from other areas within the NWTS program were now being treated on a site-specific (Yucca Mountain), host-rock-specific (welded tuff), and geohydrologic-setting-specific (unsaturated zone) basis.

**J.1.4.6 In situ tests**

As part of the concerted effort to demonstrate the utility of volcanic tuff, especially the welded variety, as a potential host rock, a multiexperiment in situ test program was devised by SNL researchers, with assistance largely from LASL colleagues (Tyler et al., 1980). The test program was designed for the G-tunnel complex that lies nearly 1400 ft below ground at Rainier Mesa, some 25 miles northeast of Yucca Mountain. Rock-mechanical, petrological, and chemical analyses were also conducted on the rocks involved in the in situ tests.

The tests were conducted in the Grouse Canyon Member of the Belted Range Tuff, a formation that, while not present at Yucca Mountain, is stratigraphically equivalent to part of the tuff sequence found there. The Grouse Canyon interval was selected for three principal reasons (1) it is largely composed of welded tuff; (2) it is the unit in which the G-tunnel complex was constructed, thus affording access as well as appreciable mining/rock stability experience; and (3) its welded tuffs displayed thermal, rock-mechanical, and other physical properties comparable to some of the welded tuffs under scrutiny at Yucca Mountain.

The initial in situ test was conducted in early 1980 (Hadley and Turner, 1980; Johnstone, 1980; Johnstone and Hadley, 1980) and consisted of a water migration/heater experiment designed to evaluate the effect of a thermal field on the high (up to 25 vol %) amount of pore water found in welded tuffs, even those within the unsaturated groundwater zone. The most significant result of this experiment revealed that the water, driven by vapor diffusion, moved toward the nearest release point or, in this case, the air-filled borehole annulus around the heater.

For much of the remainder of 1980, work at the G-tunnel test facility focused on characterization studies, identification of appropriate testing methods to address unresolved issues, and design of the actual field experiments. Based on these efforts, coupled with data from the water migration/heater experiment and various modeling the laboratory-scale studies, an interim status report on the properties of tuff as a potential repository medium was presented in late 1980 to the NAS and NRC on Radioactive Waste Management. Based on the data then available, this report concluded that moderately—fully welded tuff was an acceptable host medium where heat-generating wastes (includes spent fuel) were involved.

Additional in situ rock-mechanical and thermomechanical tests have been performed at the G-tunnel location since 1982. Evolving from the same need of earlier experiments, these tests were designed to provide data by which to evaluate/validate various predictive models, to develop generic data about welded tuffs that could be used relative to site-specific considerations, and to obtain data and experience in tuff that could be used in repository design, performance assessments, and related projects.

Another initial objective of this in situ test program was the desire to develop geotechnical instrumentation and measurement capabilities relative to the anticipated At-Depth-Test Facility. This concept and the associated ideas of a Test and Evaluation Facility and an ES were widely considered in early 1980. These topics were previously treated in Sect. J.1.4.1.

The ongoing in situ program at G-tunnel includes small-diameter heater tests and heat-blocked experiment. The latter involves the imposition of both stress and thermal loads and has led to measurements of deformation, thermal conductivity and expansion, and the permeability of natural fractures. Several different techniques to measure moisture contents have been developed and utilized (Zimmerman et al., 1981; Zimmerman, 1983). The Topopah Spring tuff was initially selected in a preliminary decision, and this study (Johnstone et al., 1984) later verified that selection.

It seems that the several in situ radionuclide-migration tests originally presented in the testing plan for the G-tunnel facility were not performed during this time period (Tyler et al., 1980).

## J.2 ACTIVITIES THAT POSTDATE THE NWPA

### J. 2.1 Period 1983–1986

#### J.2.1.1 Criteria

To execute its first responsibility under the NWPA, DOE in early February, 1983, identified nine potentially acceptable sites within six states and formally notified the governors of those states and the councils of any affected indian tribes about those identifications. Seven of these sites contained rock salt as the candidate host rock: Vacherie Dome in Louisiana, Cypress Creek and Richton Domes in Mississippi, the Swisher and Deaf Smith County sites in Texas, and Davis and Lavender Canyons in Utah. The two nonsalt involved welded volcanic tuff at Yucca Mountain Nevada and Basalt at the Hanford Site in Washington.

YM is partially within the western part of the NRDA at the NTS, but a large measure lies within the eastern sector of the Air Force (Nellis Air Force Range) and BLM lands located west of the NTS.

On May 28, 1986, it was announced that the nomination of the 3 sites (YM, Hanford, and Deaf Smith) had been approved and that site characterization activities had been authorized to proceed at each. In addition, DOE also announced that work on the second repository program (crystalline rocks) was at that time being indefinitely deferred.

#### J.2.1.2 Relationships with states, indian tribes, and the public

During the several months in early to mid-1983 when DOE siting guidelines were undergoing revision and public review, DOE established a consultation effort with the affected states, namely those having the nine potentially acceptable sites and the 17 other states where second-repository crystalline terrains were under study. As a result, DOE initiated the following steps that relate to the state of Nevada (1) mailed a copy of the guidelines to the governor and solicited his review comments; (2) conducted a series of review comment meetings at 5 regional locations (the one closest to Nevada and the NNWSI project was in Salt Lake City, Utah); (3) held an information briefing on the guidelines with state of Nevada officials and DOE staff in late March; (4) with the issuance of the alternative guidelines, conducted a plenary consultation meeting during early May in Dallas, Texas, where state of Nevada officials were present; and (5) in the course of further revision to the guidelines from review comments received thus far, held another meeting during late June in Nevada to discuss still unresolved issues within the guidelines.

Although there was criticism from both the public commentaries and state reviewers about the process of consultation itself, the inadequate time for proper review, and the several concurrence procedures, there can be little argument that DOE made a concerted effort to comply with Sect. 112 of the NWPA regarding consultation with affected states, including Nevada. Still unresolved, however, it was the process of state consultation regarding the implementation of the final guidelines. This issue was one of many that would be specified in the C&C agreement to be signed by DOE in the state of Nevada.

Section 117 of the NWPA requires that formal consultation procedures be established by means of these written C&C agreements with each state which contains a site approved for characterization and with each Indian tribe affected by the selection of these sites. By late July 1986, DOE would have a period of six months to finalize such an agreement with the state of Nevada. The specific objectives of these C&C agreements are discussed in detail within both the NWPA and in Chapter 4 of the Mission Plan. No such document was ever signed by any of the three affected states.

It should be acknowledged that since 1983, DOE has provided the six affected states and the several impacted Indian tribes with financial resources so they could more fully participate in the CRWM program. In particular, this has enabled these groups to monitor program activities, review documents, acquire technical expertise, etc. With regard to the state of Nevada, the funds have been used in part to establish a state of Nevada Nuclear Waste Project Office that is located in Carson City and reports directly to the governor. This organization also directly interfaces with the DOE/NVO located in Las Vegas.

Also of importance within the area of state consultation are the attitudes of high ranking public officials as of the state. It is a matter of record that then Governor Richard Bryan publicly voiced his opposition to the YM site when its selection was announced. Also a matter of public record are several lawsuits filed by the state of Nevada against DOE when the decision to approve the YM site for characterization was made. These lawsuits are in addition to the one previously filed with the Ninth U.S. Circuit Court of Appeals by Nevada and several other states asking that the DOE siting guidelines be overturned.

#### J.2.1.3 Technical issues

Beyond the legal questions represented by the litigation cited above, there are several general, as well as site-specific, technical issues that confront DOE and NNWSI project investigators. For the YM site, some of those directly related with certain DOE siting guidelines.

The next step in the ongoing site-selection effort concerns the generation of a detailed SCP document that outlines the data that are needed in order to accurately characterize the Yucca Mountain site, as well as the manner (types of investigations, in situ tests, etc.) in which those data are to be obtained and evaluated. As previously noted, the SCP must be prepared before the construction of the exploratory shaft can begin. Thus, the entire SCP process itself has emerged as a technical issue. Added to that are the following realizations which have evolved into related technical issues: (1) considerable criticism has come from many sources, with rebuttal from DOE officials, about the department's insistence to strictly adhere to the programmatic deadlines imposed by the overriding deadline (i.e., the 2003 waste-acceptance date, with the possible risk of sacrificing technical quality by so doing); (2) some general program slippage has already occurred; furthermore, the original milestone dates for the SCP process have not been met, new delays have caused some further, yet minor slippage, and recent concerns about quality assurance in certain NNWSI records may add still further delays; (3) the USGS has gone on record as saying that it may not be able to adequately characterize the hydrologic regime at the YM site in the allotted time, even assuming adherence to the original schedule; and (4) the threat of still further delays to the site-characterization from work from the pending litigation cannot be discounted.

YM is unique in that it was the only site under consideration where the unsaturated zone contains the prospective repository horizon. The collection and analysis of adequate data on this hydrologic regime, a regime that is not well understood nor easily modeled, is a key technical issue. An associated issue of lesser consequence is the fact that any groundwater that enters the repository will be oxidizing; this geochemical aspect is also unique to YM. A fuller understanding of this phenomenon, especially with regard to its effect upon the waste package is clearly needed.

Some general technical issues still concern the volcanic and tectonic histories of the NTS and YM proper, faults and the regional and local seismic sources that an eventual performance assessment will have to be made. The issue of faulting assumes a site-specific character in that YM is bounded on all sides by faults that have surface expression; at least one well-recognized fault, the Ghost Dance Fault, is believed to cut the potential repository horizon within the designated repository area. Beyond the potential seismic considerations represented by these faults are the related issues of whether these faults (1) will restrict the lateral extent of the prospective repository horizon, (2) will influence the mechanical characteristics of the welded tuff at repository depths, and/or (3) will reveal a potential for reactivated moment (Swadley et al., 1984). These issues are of added significance because they relate to the important postclosure guidelines of rock characteristics and tectonics.

A site-specific technical issue concerns whether there will be sufficient subsurface acreage (2,000 acres) overlain by the minimum thickness (984 ft) of overburden at the site. Preliminary studies (Mansure and Ortiz, 1984) revealed that, unless certain modifications can be made in the extent of the repository configuration (area), in the choice of the specific emplacement interval within the Topopah Spring Member, or in the thermal loading, finding enough acreage with the minimum thickness of overburden could prove to be a problem. This issue is directly related to postclosure guidelines on erosion. Another issue is the distribution of lithophysae (hollow, concentric structures composed of shells of finely crystallized minerals which formed during devitrification of obsidian) within the preferred repository horizon (Topopah Spring Member) and the relationship of these features to the thermomenchanical rock properties. There is a preference to avoid intervals of the rock that contain large numbers of these lithophysae; hence, their distribution bears on the siting guideline conditions that call for sufficient vertical and lateral extent to allow for flexibility in selecting the depth, configuration, and location of the underground facility (DOE, 1984).

In fact, there are several individual technical issues that collectively aggregate into a single criteria technical issue. Welded tuff such as that comprising the preferred repository horizon, is likely to exhibit considerable variation in intrinsic rock properties, hence in the response of the rock to seismicity. If so, the site could be difficult to characterize and in turn to satisfactorily model. Fractures pose other technical issues in the areas of hydrological modeling and an understanding of the unsaturated zone. Additional technical issues are discussed in the EA, especially in the chapters that evaluate the site in terms of the guidelines, and in the third volume, in which responses to comments on the draft EA are presented. The SCP further addresses major technical issues and general information needs.

### J.2.1.4 Programmatic organizations

One of the principal provisions of the NWPA was the establishment of the OCRWM within DOE. Section 304 stipulates that this office was to be headed by a director who would be a presidential appointee. Ben C. Rusche served in that position from May 1984 to December 1987. Chapter 5 of the Mission Plan provides a detailed discussion of the management structure and functions of the OCRWM in directing the nuclear waste disposal program according to the mandates of the NWPA. OCRWM manages the sizable financial resources provided to the Nuclear Waste Fund, as stipulated in Sect. 302 of the NWPA.

Within the functional hierarchy of OCRWM, there were four programmatic offices, one of which was the Office of Geologic Repositories. Reporting to the Associate Director of that office were the project offices responsible for the three nominated sites; each functioned through a different DOE Operations Office. In the case of NNWSI and YM there remain multiple technical contractors (SNL, USGS, and LASL) although the principal role is still exercised by SNL. Science Applications International, Inc., through its office in Las Vegas, Nevada, provides project coordination and support, as exemplified by its integration activities in the preparation of the draft and final EAs, and the final SCP. The DOE/NVO in Las Vegas continues to provide overall program supervision and administration.

Two important elements of program management that are outlined for OCRWM in the Mission Plan are (1) QA and (2) peer review. DOE has already experienced some criticism in both areas. In mid July 1986, concerns over QA regarding data collection and coring operations at YM site necessitated a "stop-work" order until record verification could be satisfactorily resolved (Crawford, 1986).

In the area of peer review, several commentators of the draft EA and an early 1985 General Accounting Office report were critical of DOE for failing to apply consistent technical-review procedures. As a counterpoint to this criticism, the following peer review relationships are relevant to the OCRWM program. First, DOE had assembled a national board of independent experts, the Performance Assessment National Review Group, to provide review on the performance-assessment efforts at all three nominated sites. Second, DOE turned again to the NAS and NRC in early 1985 for independent technical advice and review. In particular, the management plan for DOE Headquarters' SCP activities. Argonne National Laboratory was contracted to provide integrated geotechnical review of the SCPs, especially with regard to the preparation of Chapters 1–5, and their integration into Chapter 8, where the actual data-collection plan for site characterization is described in detail. Review comments by the ANL panel were made directly to DOE Headquarters. Another national laboratory, Brookhaven, also provided interdisciplinary technical review of the SCPs. All external review commentary was integrated with DOE review sources involving both the project offices and headquarters staff and managers. Thus, a balance between reviews generated both externally and internally was hoped to be achieved.

### J.2.1.5 In situ tests

Site characterization at the Yucca Mountain and the other two nominated sites will include various in situ rock tests (i.e., mechanical, thermal, hydrologic) within both the exploratory shaft and the several breakout drifts at depth. Now that DOE has decided that a TEF, if needed, can be co-located with the first respository site, additional in situ tests after site characterization are possible. Chapter 4 of the final EA briefly described the number and general types of anticipated tests. The SCP, especially Chapter 8, outlined in detail the tests to be performed at the Yucca Mountain site.

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# APPENDIX K.
# THE DEAF SMITH COUNTY SITE, TEXAS

## K.1 DISCUSSION

Early interest in bedded salt deposits of the Permian Age in the southwest region of the country was initially directed to areas in Kansas and New Mexico. Later, during the mid-1970s, attention shifted to the Permian salt deposits of western Oklahoma and Texas. In part, this was caused by (1) the realization that further studies on salt in Kansas would no longer be politically feasible and (2) because the WIPP in southeastern New Mexico would not remain a part of the NWTS program. That is, the WIPP site was to be used only for defense wastes.

By April 1976, a regional reconnaissance was completed on three subbasins (Anadarko, Palo Duro, and Dalhart) of the Permian Basin in western Oklahoma and the panhandle of Texas (Johnson, 1976). This work generated new information about the lithology, thickness/depth, distribution, structural geology, and dissolution behavior for a major evaporite sequence that underlies a large area in these states.

The purpose behind the reconnaissance study was three-fold (1) to establish a better understanding of the stratigraphic/structural framework for the middle of central part of the Permian Basin (which had been less well studied than portions to the northeast and southwest); (2) to determine whether the evaporite sequence contained salt beds of appropriate thickness, purity, and lateral continuity at acceptable depths; and (3) to evaluate the relative potential of the three subbasins as sources of repository sites. Specific screening criteria that were applied in this regional reconnaissance were (1) number and thickness of individual salt beds; (2) depths to sufficiently thick salt-bearing units; (3) percentage of salt within the salt-bearing units along with the regional distribution of each unit; (4) regional seismicity; (5) density of existing boreholes that penetrated the evaporite sequence; (6) areas where salt, brines (natural and solution-mining), oil, gas, and other minerals were being extracted; included also were hydrocarbon-storage caverns; and (7) areas and specific salt beds known to be affected by natural salt dissolution. The distribution of regional saline and fresh water aquifers was also considered in general terms, but not used as a screening criterion.

On the basis of the above criteria, this study indicated that the Palo Duro and Dalhart Basins were more favorable than the Anadarko Basin. One of the more influential considerations was that these two subbasins appeared to exhibit much less potential for occurrences of oil and gas and consequently had been less extensively drilled. The Palo Duro Basin was additionally preferred because it contained more salt units of greater areal extent than the Anadarko Basin. The study recommended that further studies be undertaken on both the Palo Duro and Dalhart subbasins and specified several of the geotechnical parameters that needed to be evaluated.

As later described in the final EA for Deaf Smith County (Palo Duro Basin) nominated site (DOE, 1986), the work mentioned above was identified as the geologic characterization documentation by which the site-selection (i.e., screening) process moved from a national level to a regional level. An earlier USGS publication (Pierce and Rich, 1962) was identified as the national-survey document; the subsequent Johnson and Gonzales (1978) report reaffirmed those findings.

During 1977 and 1978, the following activities were undertaken for the Palo Duro and Dalhart subbasins: (1) TBEG was engaged in 1977 to conduct a wide range of geologic and hydrologic studies of the salt-bearing stratigraphic sequence and to examine the causative agents for dis-solutioning of the salt beds (Dutton et al., 1979; Gustavson et al. 1980, 1981, 1982, 1983). While these TBEG activities are not part of the siting-record documentation, they did generate appreciable data and relate interpretations that collectively affected certain siting decisions. (2) DOE, TBEG, and others planned a stratigraphic drilling program. The two initial test boreholes (DOE/Gruy Federal, Inc.; Rex White, Jr., No. 1 in Randall County, and DOE/Gruy Federal, Inc. D. M. Grabbe, No. 1 in Swisher County) were drilled in 1978. These and several subsequent boreholes drilled during 1981–1983 provided important subsurface stratigraphic, lithologic, and hydrologic data that would eventually be used in the siting process. (3) In August 1977, the NUS Corporation was selected as the Regulatory Project Manager for the two bedded-salt regions (Silurian Salina Group within the Michigan and Appalachian Basins, and the Permian Basin). Initial draft versions of the Regional Environmental Characterization Reports for both regions were prepared by this firm in early to mid-1978. Although a revised edition of the Permian Basin draft was later submitted for distribution, this document was not completed and issued until 1983 (NUS Corporation 1983*a*). Even though this delayed report served as part of the basis for the documentation by which the Palo Duro and Dalhart Basins were recommended for area characterization (Battelle, 1979), the selection of these two subbasins as study areas had essentially been made nearly 5 years earlier.

The status of Permian Basin activities in mid-1978 can be summarized as follows: (1) TBEG was the principal organization conducting geotechnical studies within the Palo Duro and Dalhart Basins, (2) a GPM had not yet been selected, (3) an active stratigraphic test drilling program was just beginning in the Palo Duro Basin; (4) the Draft Regional Environmental Characterization Report (NUS Corporation, 1978), as noted previously, was found to require extensive revision in response to reviewers' comments.

During the next 5 years a number of important geologic and environmental characterization and siting documents were issued. These reports and two subsequent DOE publications released in 1984 are summarized in the Deaf Smith County EA (DOE, 1986) and represented the record of the required screening documentation. The area environmental characterization of the two subbasins (Dalhart and Palo Duro) is provided by a two-volume report (NUS Corporation, 1982).

The study area recommendation report (Battelle, 1979) used the following criteria in making its region-to-area screening; (1) thickness and depth of salt-bearing units; (2) faulting and seismicity; (3) salt dissolution; (4) boreholes and subsurface mines; (5) proximity to aquifers; (6) presence of mineral resources, including oil and gas; (7) conflicting land use; and (8) exclusionary land areas such as national parks, state parks, and historic sites where more than 1,000 acres were protected. On the basis of these criteria, the Palo Duro and Dalhart Basins were selected from the five subbasins of the Permian Basin for these reasons: (1) both basins contained numerous salt-bearing formations greater than 200 ft in thickness (Note: The formations that contained the salt beds were of that thickness, an individual salt bed was not necessarily that thick) and within a depth range of 1,000–3,000 ft.); (2) both basins exhibited low levels of seismicity; (3) both basins lacked any major oil and gas fields, as well as other significant mineral deposits of economic value; (4) both basins had relatively few boreholes that penetrated the entire salt-bearing sequence; (5)both basins revealed no evidence that salt was being naturally dissolved below a depth of 1,400 ft.; and (6) both basins lacked other significant factors that would rule them out for further study.

Even though TBEG would continue as an active technical participant within the Permian Basin, the need developed for a GPM that could provide overall management in organizing, and presenting for publication, the geologic and hydrologic data being developed. A GPM also became necessary because (1) TBEG was willing to publish only through its own outlets, and (2) TBEG viewed its geotechnical involvement from a research perspective and was reluctant to become involved in those activities that were part of the site-selection process. In 1980 SWEC was chosen by ONWI as the Permian Basin GPM.

SWEC's initial responsibility within the Permian Basin was to compile the Area Geologic Characterization Report for the two selected subbasins (Dalhart and Palo Duro). The initial draft of that document was completed in February, 1981. Because of revisions, and additions of new data and other interpretations, this screening document was not completed until July, 1983 (Stone and Webster Engineering Corp., 1983). Contributing to the delay were numerous differences of opinion between ONWI, SWEC, TBEG, and DOE officials, as well as criticisms received from the Texas Energy and Natural Resources Advisory Council and other reviewers in Texas.

In addition to the work described above, ONWI and SWEC worked cooperatively with TBEG officials in an integrated test drilling program to provide supplemental subsurface data to that obtained from the White and Grabbe wells drilled in 1978. During 1981—82, seven new boreholes were drilled. Data from all of these boreholes were combined with seismic-reflection profiles to improve the understanding of the stratigraphy within the Deaf Smith and Swisher Counties portion of the Palo Duro Basin.

Several of the siting criteria contained in the DOE Siting Guidelines would shortly be applied to discriminate between the Palo Duro and Dalhart Basins, and to also identify preferred locations within the Palo Duro Basins. As indicated in the Deaf Smith County EA (DOE, 1986), the Permian Basin Location Recommendation Report represents the documentation for the area-to-location phase within the screening process (OWI, 1983). This study was initially released for review in November 1982. As described in its Appendix D, the Texas Energy and Natural Resources Advisory Council and several other Texas organizations provided review commentary into mid-1983. The presentation of DOE responses required nearly four months, and thus the revised final was not issued until September, 1983.

The LRR relied upon only five of the ONWI/NWTS site performance criteria (DOE, 1981), and a total of eight subcriteria (termed subcriteria in the report itself on page 70, but renamed technical factors on pg 2—9 of the Deaf Smith County EA) (DOE, 1986). For each of the subcriteria, a screening specification was established. For example, under site geometry, the specifications for minimum and maximum depths are 1,000 and 3,000 ft, respectively; also specified was a minimum salt-bed thickness of 125 ft.

Two important site-screening decisions were reached: (1) the Dalhart Basin failed to meet the minimum salt-bed-thickness screening specification and was subsequently eliminated from further study and (2) six locations were identified within the Palo Duro Basin as satisfactorily meeting all the site-performance criteria, subcriteria, and related screening specifications. In addition to considerations of geometry, the report used the following screening criteria: (1) salt purity (as defined by a particular response in American Petroleum Institute units on a gamma ray borehole log); (2) avoidance of operating or abandoned oil and gas fields; (3) avoidance of flood-prone areas adjacent to perennial streams; and (4) avoidance of wildlife refuges and water reservoirs.

The six satisfactory locations were situated in the following counties: Deaf Smith; Swisher; Randall and Potter; Swisher and Briscoe; Potter; and Armstrong. By applying additional parameters selected specifically, Deaf Smith and Swisher Counties were chosen as the preferred locations and consequently were recommended for further study.

During the period of time (November, 1982 through September, 1983) that the Location Recommendation Report was initially issued, reviewed, revised, and released in final form, Secretary of Energy Donald P. Hodel, in February 1983, sent formal notification to the Governor and the Legislature of Texas that their state was considered to contain two potentially acceptable sites. In November, 1984, a three-volume final report was issued (DOE, 1984). Discrimination among the six satisfactory locations was undertaken by the following approach: (1) selected NWTS site performance criteria (DOE, 1981) were applied because it was felt that they would display variations among the locations and thus be useful in discriminating between them; (2) siting criteria were grouped and ranked in terms of their significance relative to the following considerations: long-term performance, operational performance, environmental effects, and constructability effects; and (3) a map-overlaying process was applied by which a composite map of the grouped and ranked criteria reduced the available land to a preferred site of the desired size (≈9 miles$^2$). The two resulting sites were then identified as the Deaf Smith County and Swisher County sites.

When subjected to review, DOE's decision on site selection received a considerable number of critical comments from individuals, organizations, and the Texas Nuclear Waste Programs Office. Some repositioning of the two preferred sites by the DOE was one outgrowth of this public review.

By late 1984, when the final DOE siting guidelines had been published and NRC concurrence had been received, the draft EAs for the nine potentially acceptable sites nationwide were released. DOE had also decided that, in order to comply with the NWPA, it would be appropriate to identify the five sites slated for nomination at this stage in the siting process and thus only issue final EAs for those sites.

The Deaf Smith County site was selected as more favorable than the Swisher County site on the basis of a comparison of one postclosure and five preclosure guidelines, where the available evidence revealed that differences between the sites could be demonstrated. The actual differences between the sites, the relative importance of the six guidelines involved, and the weighted analysis whereby the selection decision was reached are described in detail in Sect. 2.4 of the Deaf Smith County EA (DOE, 1986).

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# APPENDIX L.
# CRYSTALLINE REPOSITORY PROGRAM: NATIONAL SCREENING DOCUMENT AND REGIONAL GEOLOGIC CHARACTERIZATION REPORTS

## L.1 DISCUSSION

Studies of the suitability of crystalline rocks in the southeastern United States. were conducted by the Savannah River Plant and its subcontractors (see Sects. 3.2.2 and 5.1.2). In 1979, DOE initiated a nationwide reconnaissance of crystalline rocks (see Appendix I) in response to recommendations made by the Interagency Review Group (1979). Although the draft report (Dames and Moore, 1979) resulting from the National reconnaissance had much useful information, it was severely criticized by technical reviewers and DOE (in part because some of the conclusions were not supported by the data) and the effort was subsequently suspended by DOE. Although no final report was ever issued, objective data from that draft report taken together with the information from a report by the USGS (Smedes, 1980) constituted a sufficient interim basis for DOE to conduct regional investigations in the Lake Superior, Northern Appalachian, and Southern Appalachian regions (programmatically referred to as the Northern Central, Northeastern, and Southeastern Regions, respectively).

In October 1982, DOE initiated a national survey of crystalline rocks. That Office of Crystalline Repository Development study 1983, which built upon, and drew heavily from, the USGS report (Smedes, 1980), documents the decision for selecting the three regions under investigation in the crystalline repository project, namely, the Lake Superior, Northern Appalachian, and Southern Appalachian Regions.* The OCRD report was not a revision of the suspended draft report, but was a new document which provided information and logic to support the regional recommendations resulting from the national reconnaissance and evaluations. The document built on Smedes' earlier work (1980) and incorporated some of the regional description from the sources also used in the draft reconnaissance, as well as other relevant data and concepts from more recent sources. OCRD-1 was responsive and included resolution of pertinent issues and substantive comments raised through state reviews of the draft reconnaissance. Although OCRD-1 did not go through any formal consultation and concurrence procedure, it did address the state issues. Input to the report was provided through review by ten people from DOE, Battelle Project Management Division, OCRD, USGS, and EG&G, some of whom had been involved in discussions with state officials critical of the draft reconnaissance.

A report by the Minnesota Governor's Nuclear Waste Council (1986) submitted as part of the Governor's testimony during a Congressional hearing was highly critical of DOE's "National Survey of Crystalline Rocks." DOE's detailed response (DOE, 1984*a*) pointed out that the authors of that Minnesota report had mistakenly commingled and confused the draft 1979 reconnaissance report—which DOE had suspended —with the true national survey of 1983, and therefore the criticism was unfounded.

In the 1983 report which served as the national screening document for the crystalline rock program (OCRD, 1983), the siting criteria were in large measure based on selected site-performance criteria promulgated the previous year (1982). These draft regulations were essentially the same as minimum depth of the repository horizon (1,000 ft) and groundwater travel time from the repository to the accessible environment (minimum of 1,000 years).

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* The investigations were conducted in Michigan, Minnesota and Wisconsin; Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont; and Georgia, Maryland, North Carolina, South Carolina, and Virginia, respectively.

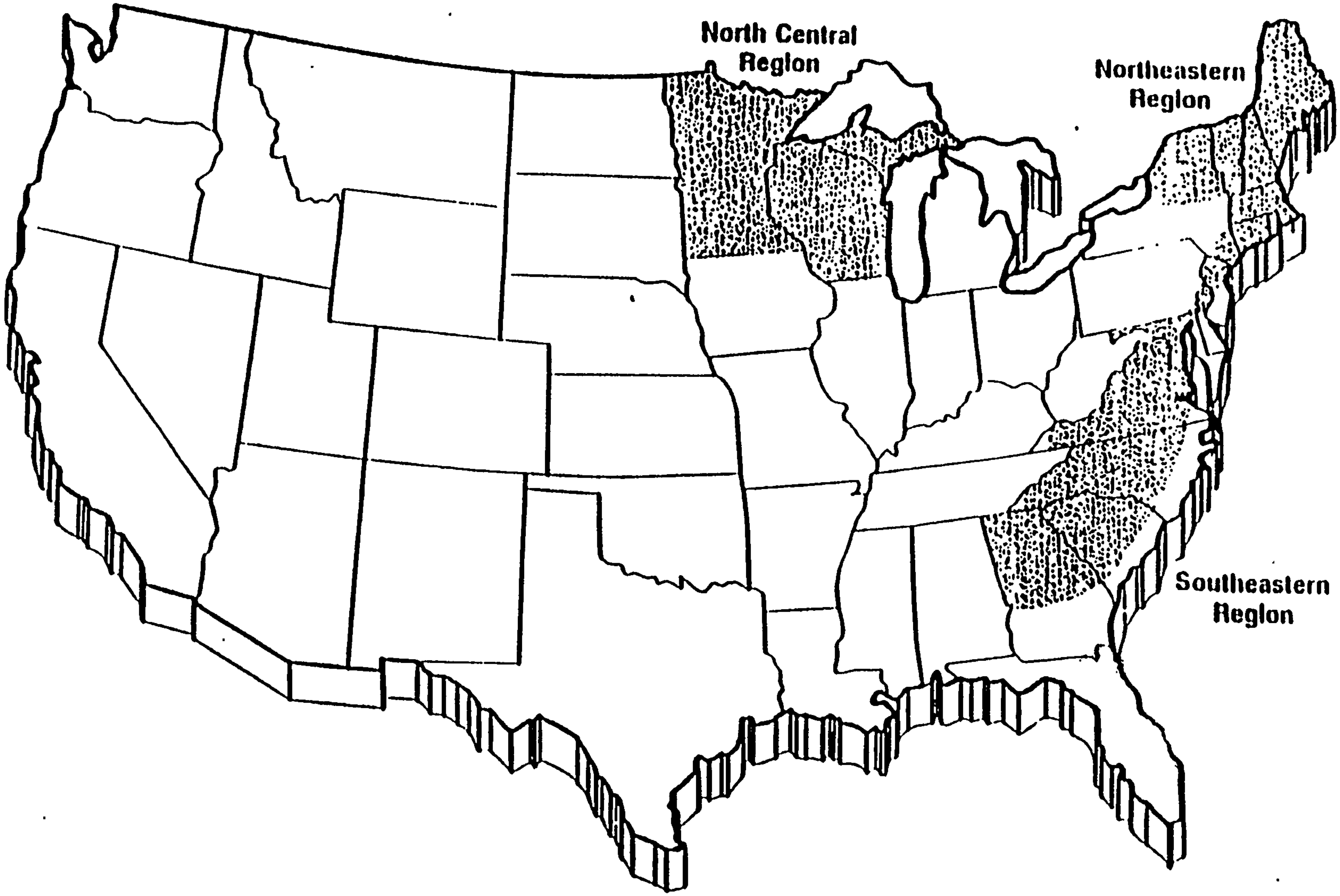


Fig. L.1. Regions of crystalline rock considered for the second repository.

The NRC presented 6 favorable conditions and 21 potentially adverse conditions in their draft criteria. H. Smedes, who was the author of the 1983 OCRD report noted previously above, used one of the former (in addition to the criterion of minimum depth) and eight of the latter to evaluate the regional potential of exposed crystalline rocks. Existing nationwide data did not permit the utilization of the other NRC draft criteria. His specific evaluation factors included (1) areas of exposed crystalline rocks; (2) vertical crustal movement less than 3,280 ft in the last 10 million years; (3) absence of young (quaternary) faults; (4) absence of known earthquake epicenters with intensities of V or greater on the Modified Mercalli Scale; (5) probable lateral acceleration (due to seismic events) of less that 10% g in the next 50 years; (6) absence of quaternary volcanic rocks or deposits; (7) absence of known metallic and certain nonmetallic deposits; (8) absence of high-temperature convection (geothermal steam) systems; (9) absence of extreme erosion in the quaternary; and (10) absence of potentially high regional hydraulic gradients.

The first eight factors were displayed graphically in a series of overlay maps such that all are of equal weight. The resulting composite maps revealed those regions in which exposed crystalline-rock masses are present but which lack such potentially adverse conditions as appreciable vertical movement, young faults, high seismicity, etc. The National Atlas (USGS, 1970) map sheet of relief was then used to visually screen out those areas of the composite map that are characterized by high relief. Such areas represent areas of extreme erosion (factor 9) and areas of probable high hydraulic gradients (factor 10)—and of potentially inaccessible terrain.

In reaching the final recommendation of three regions (North Central, Northeastern, and Southeastern), some additional considerations were employed because an absolute, objective ranking of all regions was not possible given the generalized and qualitative nature of the input data. These considerations dealt with the likelihood of finding suitable sites expeditiously.

For each of the three regions recommended in OCRD-1 for further study, regional geologic characterization reports (RGCRs), and review draft, revised draft, and final environmental characterization reports were prepared and issued. Geologic, hydrologic, and environmental (including demographic) data that could ultimately be employed as either disqualifying factors or screening variables in subsequent site-selection activities were assembled in these reports. The overriding basis for these considerations relates to the DOE Siting Guidelines (DOE, 1984*b*). Several national laboratories (Argonne, Oak Ridge, and Pacific Northwest) and consulting contractor firms (Woodward-Clyde Consultants, Golder and Associates, and The Earth Technology Corporation) participated in the preparation of the several draft reports; all final reports were prepared by the Office of Crystalline Repository Development for the DOE (DOE 1985*a*–*c* and 1985*d*–*f*).

These siting factors and screening variables that are incorporated in the final versions of these RGCRs include the presence of deep mines and quarries, rock-mass extent, post-emplacement faulting, suspected quaternary faulting, seismicity, rock and mineral resources, major groundwater discharge zones, groundwater resources, state of (rock) stress, thickness of rock mass, and thickness of overburden. Considerable geologic information is presented that provides background documentation for being able to utilize these disqualifying factors and screening variables. Thus, for each crystalline rock body, data on geologic age, areal extent, thickness, shape, texture and composition, degree and type of alteration, and associated structural features were also assembled. Data on regional tectonics and seismicity were also compiled; other information on mineral resources, extraction operations, local and regional groundwater hydrology, landform development, and surficial materials and processes were included as well. All data came from the available literature and other publicly available sources; no field activities were performed.

As previously noted, both disqualifying factors and regional screening variables are based on provisions of the DOE Guidelines (DOE, 1984*b*). Disqualifying factors consist of conditions that are unacceptable to repository siting, and therefore they can be used to eliminate land units, rock bodies, or parts of either from further consideration. Regional screening variables embrace regional data that can be utilized to establish the relative favorability of land units and/or rock bodies.

The draft RGCRs for all three regions identified some 235 crystalline rock bodies that were believed to meet two criteria (1) the rock bodies had to extend to a depth of at least 1,000 ft below the land surface and (2) they had to exhibit an areal extent of at least 39 square miles. The specific purpose of the disqualifying factors and screening variables was to eventually narrow the sizable number (235) of rock masses down to a more workable number of potentially acceptable sites through the Region-to-Area Screening Process (DOE 1985*g*). Each final RGCR also contains a summary chapter that discusses the intended use of the geologic data in this next screening step; a similar treatment is afforded the environmental data in the companion environmental characterization reports.

The RGCRs were issued by OCRD in the original draft format in early 1983 and underwent extended critical review by the 17 affected states in the 3 regions, the USGS, DOE officials, and internal peer review panels assembled by the various contractor firms.

Revised drafts of the RGCRs were released in late 1984, as were incorporated comments (both written and from verbal discussions at various meetings) from the review sources just cited. Additional revision to the revised drafts was necessitated by further commentary from several states and the USGS; these comments and related corrections were integrated into the final RGCRs which were issued in mid-1985.

The regional-to-area screening methodology entailed appreciable involvement from representatives of the 17 affected states. Various workshops were held whereby the most useful siting variables could be assigned weighting (relative importance) values. From these federal-state interactions, 9 sets of weighted or scaled variables were chosen by which to compare and rank the 235 rock bodies (DOE, 1985*g*).

By applying the above methodology, 11 potentially acceptable sites were selected, respectively, in the states of Georgia (1), Maine (2), Minnesota (3), New Hampshire (1), North Carolina (2), Virginia (2), and Wisconsin (1) (DOE, 1986). Considerable opposition and criticism was soon forthcoming, from a broad cross-section of the general public, politicians, and industrial groups in the affected states.

In mid-1986, DOE Secretary Herrington announced that site-specific work under the crystalline program was being indefinitely postponed. Reasons given for this decision included (1) declines in the generation of spent fuel that greatly lessened the need for a second repository; (2) appreciable progress that had been achieved in the first repository program, as evidenced by the recommendation of, and Presidential acceptance of, three sites for characterization; and (3) the expectation of a monitored retrievable storage (MRS) facility and its benefits to the entire waste-disposal program. Critics, especially those in the western states where this decision adversely affected the regional balance that had produced the NWPA, strongly contend that the DOE postponement decision was motivated purely on political grounds. L. J. Carter (1987) discussed certain indications that support this contention.

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## APPENDIX M.
## WASTE CONFIDENCE RULEMAKING

## M.1 DISCUSSION

A lengthy series of events led to a formal rulemaking procedure to address the degree of assurance available that radioactive waste can be disposed of safely, when such disposal will become available, and whether radioactive waste can be stored safely on-site beyond the expiration of reactor licenses until an off-site facility becomes available. This rulemaking is widely referred to as the Waste Confidence Rulemaking. The background and sequence of events in this rulemaking are summarized as follows:

1. In 1972, the AEC instituted a generic proceeding known as the "S-3 proceeding" whose purpose was to specify the environmental impacts of the uranium fuel-cycle activities to support the operation of a light-water reactor.

2. AEC issued a final rule in 1972. The Natural Resources Defense Council (NRDC) sued, and the U.S. Court of Appeals for the District of Columbia reviewed the fuel-cycle rule and remanded it to NRC since the record before it was inadequate. NRC then prepared a supplemental *Nuclear Regulatory Guide* and issued an interim rule in March 1977.

3. In November 1976, the NRDC petitioned NRC for a rulemaking to determine whether radioactive wastes generated in nuclear-power reactors can subsequently be disposed of without undue risk to the public health and safety. The NRDC also requested that NRC not grant pending or future requests for operating licenses until the petitioned finding of safety was made.

4. On June 27, 1977, the NRC denied the NRDC petition and stated that NRC would not refrain from issuing reactor operating licenses until the disposal problem was solved because there is reasonable confidence that the wastes can and will be disposed of safely.

5. In November 1977, two nuclear power plant licensees had requested amendments to their operating licenses to permit expansion in the capacity of their spent-nuclear-fuel assembly pools. The New England Coalition on Nuclear Power and the Minnesota Pollution Control Agency intervened. The NRC staff did not believe that there would be any potential environmental effects of their operating licenses. Minnesota appealed their decision to the U.S. Circuit Court of Appeals. The NRC staff finding was affirmed by the licensing board panel and the licensing appeals panel.

6. In the interim, the 1977 Comptroller General's Report to Congress (Comptroller General, 1977) warned that the growth of nuclear power in the United States was threatened by the problem of how to safely dispose of the radioactive waste. The report contained several findings and recommendations on how to improve waste management so as to provide assurance that public health and safety are considered in all matters of nuclear-waste management.

7. NRDC filed suit in 1977 (*Federal Register, 42*, 34391). The District of Columbia Court held (582 F. 2*d* 166, 1978) that the issue of waste confidence did not have to be addressed in an adjudicatory proceeding and that Congress had relied on NRC's and AEC's assurances of confidence that a solution to the issue of waste disposal will be reached. The court remanded the case to NRC for further consideration in light of the ongoing S-3 proceeding.

8. On May 29, 1979, the court declined to stay or vacate the license amendments which had been appealed by Minnesota but remanded to NRC the question of whether there is reasonable assurance that an off-site storage solution will be available by the time of expiration of the plants' operating

licenses and, if not, whether there is reasonable assurance that the fuel can be safely stored at the reactor sites beyond those dates.

9. In response to the Court's remand of the NRDC suit to the NRC and to the decision of the Appeals Court in the State of Minnesota vs NRC, the NRC initiated rulemaking on October 18, 1979, to reassess generically its degree of confidence that radioactive waste can be disposed of safely, to determine when such disposal will become available, and whether radioactive wastes can be stored safely on-site past the expiration of reactor licenses until an off-site facility becomes available.

10. DOE issued a Statement of Position (DOE, 1980) and, in response to Prehearing Conference Order (NRC, 1980), issued a Cross-Statement (DOE, 1980) which discussed the various issues raised in 33 Statements of Position files by other participants (DOE, 1980), (Tab. I–1, p. I–2).

11. NRC issued the Waste Confidence Decision on August 31, 1984 (*Federal Register, 49, 34658*) and made five findings of reasonable assurance that (a) safe disposal of HLW and spent fuel in a mined geologic repository is technically feasible and achievable using existing technology, (b) one or more geologic repositories will be available by the year 2007–2009 and sufficient repository capacity will be available within 30 years beyond expiration of any reactor operating licenses to dispose of HLW and spent fuel originating in such reactors and generated up to that time, (c) HLW waste and spent fuel will be managed in a safe manner until sufficient repository capacity is available to assure the safe disposal of all HLW and spent fuel, (d) spent fuel generated in any reactor can be stored safely without any significant environmental impact for a least 30 years beyond the expiration of the reactor's operating licenses at the reactors' spent-fuel storage basins or on-site or off-site independent spent-fuel storage installations, (e) safe independent on-site or off-site spent-fuel storage will be made available if such storage capacity is needed.

12. The NRC is committed to reviewing its conclusions on waste confidence should significant and pertinent unexpected events occur (or at least every five years) until a repository is available. The next review was to be August 31, 1989.

13. Enactment of the NWPA contributed significantly to the basis for the NRC 1984 decision and companion rulemakings. The act established a funding source, process, milestones, schedules, development of a MRS facility, repositories, and requirement of conduct in situ investigation.

In DOE Statement and Position in the Matter of the Proposed Rulemaking (DOE, 1980*b*) direct storage and disposal of spent fuel was addressed as the representative case. This was done in view of the fact that the President had indefinitely deferred all civilian reprocessing of spent fuel (President Carter, 1977). Thus, the NRC needed only to find reasonable assurance (confidence) that spent fuel in some form could be safely stored and disposed of by any single method. Furthermore, the Presiding Officer of the proceeding had ordered that the proceeding was to be concerned solely with high-level waste.

In its Statement of Position, DOE presented detailed data and analysis to provide the basis for a finding that spent nuclear fuel from licensed facilities could be disposed of safely within a reasonable time. Further, the technical basis for construction of off-site storage/disposal facilities and the capability to provide them is available now. On that basis, DOE submitted that spent nuclear fuel could be both stored and disposed of safely off-site.

The Statement of Position described in considerable detail the background and technical status of repository development. It set forth a detailed program and schedule for establishing geologic repositories within a variety of host rocks and geographic regions in a safe, environmentally acceptable manner. It adopted a conservative approach and identified the mined geologic disposal concept as the focus of DOE's waste-management planning strategy.

The Statement of Position pointed out that the major decision associated with geologic disposal involved site selection, which included state consultation and concurrence and repository licensing. The DOE program provided for the selection of candidate sites by a systematic process that included consideration of all applicable geologic, hydrologic, tectonic, and resource factors to be carried out in three phases (1) site exploration and characterization; (2) detailed site characterization; and (3) site selection.

The site exploration and characterization phase involved geologic and environmental studies to obtain the technical data that became increasingly specific as the selection process narrowed to specific locations and sites. Steps in the site-characterization process were:

- National screening surveys.
- Determination of regions for further study (up to several states in extent).
- Recommendation of areas for more detailed investigation [up to 2,600 $km^2$ (1000 $mile^2$)].
- Recommendation of specific locations for in-depth study [up to 78 $km^2$ (30 $mile^2$)].
- Recommendation of preferred sites for candidate repositories [nominally 26 $km^2$ (10 $miles^2$)].

The detailed site-characterization phase would involve the collection of all additional data that would be necessary in order to apply for a license for that site. It would require extensive drilling to obtain geologic and hydrologic information, laboratory and field testing of rock and water samples, and closely-spaced geophysical surveys.

The process of selecting a site and applying for a license to construct a repository would be initiated after four or five sites in different geologic settings were found to be suitable, and would include a comparison of environmental and technical factors plus the legal, political, and institutional considerations.

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