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THIRD REPORT TO THE U.S. CONGRESS AND THE U.S. SECRETARY OF ENERGY

FROM THE

NUCLEAR WASTE TECHNICAL REVIEW BOARD

May 1991

DISCLAIMER

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
1100 Wilson Boulevard, Suite 910
Arlington, VA 22209

May 29, 1991

The Honorable Thomas S. Foley
Speaker of the House
United States House of Representatives
H-204 Capitol
Washington, D.C. 20515-6501

The Honorable Robert C. Byrd
President Pro Tempore
United States Senate
Hart Office Building, Suite 311
Washington, D.C. 20510-1902

The Honorable James D. Watkins
U.S. Secretary of Energy
U.S. Department of Energy
Forrestal Building
Washington, D.C. 20585

Dear Speaker Foley, Senator Byrd, and Secretary Watkins:

The Nuclear Waste Technical Review Board (the Board) herewith submits its third report as required by the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203.

Congress created the Board to evaluate the technical and scientific validity of activities undertaken by the Department of Energy (DOE) in its civilian high-level radioactive waste disposal program. The Board is charged with evaluating the DOE's characterization of Yucca Mountain as a potential location for a repository for the permanent disposal of high-level radioactive waste. The Board also is evaluating activities relating to the packaging and transportation of high-level waste and spent fuel.

Since its last report in November 1990, the Board has continued interaction with the DOE, listened to assessments of the DOE's site-characterization efforts by the State of Nevada and others, and obtained and reviewed technical and scientific information on the DOE's program.

In this report the Board evaluates its interactions with the DOE and other organizations. It also assesses information from other sources and comments on recent developments at the DOE.

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At this time, the Board has no specific recommendations that require congressional action. It does, however, make a number of recommendations regarding the DOE program for radioactive waste management that are intended to improve ongoing technical work.

We thank you for this opportunity to serve the nation and Congress. As our work progresses, we hope to assist Congress and the DOE in furthering the goal of safe, efficient, and timely disposal of civilian high-level radioactive waste.

Sincerely,

Don U. Deere, Chairman

Clarence R. Allen

John E. Cantlon

Melvin W. Carter

Patrick A. Domenico

Donald Langmuir

D. Warner North

Dennis L. Price

Ellis D. Verink

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Executive Summary

By the year 2000, the United States will have a projected 40,000 metric tons of spent nuclear fuel stored and awaiting disposal at some 70 sites around the country. By 2035, after all existing nuclear plants have completed 40 years of operation, there will be approximately 85,000 metric tons. The amount of spent fuel needing disposal will continue to grow with the relicensing of existing nuclear plants and possible construction of new facilities. In the Nuclear Waste Policy Act of 1982, Congress assigned to the Department of Energy (DOE) the responsibility of designing and developing a system to manage the disposal of this spent fuel plus approximately 8,000 metric tons of defense high-level waste from reprocessing.

In a 1987 amendment to the Nuclear Waste Policy Act, Congress created the Nuclear Waste Technical Review Board (the Board) as an independent source of expert advice on the technical and scientific aspects of the DOE's program.

The Board holds meetings and public hearings with representatives of the DOE and its contractors, other federal agencies, and the national laboratories, as well as with representatives of the State of Nevada and organizations concerned with high-level waste management issues. The Board also tries to remain apprised of the progress being made by other countries with high-level radioactive waste management programs.

The Board is required to report its findings and recommendations to Congress and the Secretary of Energy at least twice a year. In its reports, the Board reviews its findings and makes recommendations that are intended to improve the technical and scientific work the DOE is conducting at the proposed repository site at Yucca Mountain, Nevada, and to assist the DOE in its overall plan to study and characterize the site and develop a high-level radioactive waste management program.

A. Board Activities During this Reporting Period

The Board publishes two reports each year, in the fall and in the spring. The *First Report* was released in March, the *Second Report* in November 1990. The third report reviews activities undertaken by the Board and its panels from August 1, 1990, to January 31, 1991.

During this reporting period, the Board held two full Board meetings: October 10, 1990, and January 15-17, 1991, in Arlington, Virginia. In addition, members attended 13 Board-sponsored panel meetings and public hearings. Members met with the DOE and its contractors, as well as with representatives from the Environmental Protection Agency, the Nuclear Regulatory Commission, the State of Nevada, the United States Geological Survey, the Western Shoshone National Council, and the utilities. Members of the public and representatives of environmental and other organizations also attended the public hearings and some of the technical meetings. Board members have attended a variety of technical exchanges, conferences, symposia, and workshops. They also have participated in field trips to examine geologic formations in Nevada.

The Board spent one week visiting with scientific and technical experts in Sweden and the Federal Republic of Germany in June 1990. The Board made a number of observations during the trip that have been included in this report.

In September 1990, Dr. Deere, Board Chairman and Dr. Carter, chair of the Panel on Environment & Public Health, presented the Board's concerns about regulatory standards at a two-day symposium hosted by the National Research Council. In October 1990, Dr. Deere testified before the Subcommittee on Nuclear Regulation of the Committee on Environment and Public Works in the U.S. Senate. Both of these activities were discussed in more detail in the *Second Report.*

On March 21, 1991, Dr. Deere testified before the Senate Committee on Energy and Natural Resources. Because of its timeliness, his testimony is discussed in this report. Dr. Deere was asked to respond to two questions put to him by the Committee: (1) Is the Department of Energy prepared to initiate site-characterization activities? (2) Is there any reason to disqualify the Yucca Mountain site at this time?

In answer to these questions, Dr. Deere stated that, in the Board's view, the DOE is prepared to begin a progression of site-characterization activities as soon as it has gained access to the site. The Board is in agreement that the DOE should proceed with its assessment of the Yucca Mountain site. Given existing data, there appear to be no *scientific* or *technical* reasons to abandon the site at this time. It is conceivable, however, that disqualifying conditions may be identified as the site is being characterized.

B. Recommendations

The recommendations made in the Board's reports are intended to aid the DOE in its efforts to improve the technical and scientific work being conducted in its high-level waste management program. As a result of activities during the past six months, the Board makes the following recommendations, which are organized according to the Board's panel activities.

Structural geology and geoengineering

1. The DOE should reexamine its test plans to ensure that the saturated zone of the Calico Hills unit and Prow Pass member will be adequately evaluated—considering its appreciable contribution to waste isolation as determined in the CHRBA study.

2. The DOE should continue with the preliminary design of the ESF on the basis of the selected and optimized version of the three highest-ranked options from the ESF alternatives study.

3. The DOE should continue with repository conceptual design throughout the design phases for the ESF. Different geometric layouts and thermal-loading alternatives for the repository should be explored.

Engineered barrier system

4. High priority should be assigned to developing a more robust engineered barrier system. A workshop on engineered barriers, which was recommended in the Board's *Second Report* and which has been scheduled for June 18-19 in Denver, Colorado, is a logical first step.

5. The Board recommends that the DOE seek clarification of some NRC regulations. The NRC should be able to provide definitions for terms like "substantially complete containment" and the "proof to be required to demonstrate such containment."

Transportation and systems

6. A workshop should be scheduled on ways to minimize the handling of waste in the life-cycle process. The workshop should address the interactions among the major system components — storage, transportation, and disposal. The scope should include potential technologies, possible regulatory impediments, and institutional incentives and barriers to such an integrated system.

Environment and public health

7. The DOE should consider developing a comprehensive regional program to expand the public's understanding of the potential risks associated with the development of a high-level nuclear waste repository, as well as of other nuclear and non-nuclear activities. Special efforts should be made to develop a dialogue involving non-DOE experts.

8. The EPA and the NRC should be encouraged to modify and clarify 40 CFR 191 and 10 CFR 60, respectively. The regulations should be risk based, fully protective of public health and the environment, but not too prescriptive. In addition to being consistent and mutually compatible, they should be presented in a clear and understandable manner and be applicable to and defensible in the licensing arena. Furthermore, they should reflect current internationally accepted environmental standards and be compatible with the uncertainties intrinsic to long-term geologic processes.

Quality assurance

9. The Board praises the DOE for initiating a two-way process to identify and resolve QA implementation issues that have been identified by DOE management and researchers. The Board concurs with the DOE's QA managers that the QA process should not be coupled with highly detailed management/administrative procedures. The Board recommends that the DOE continue this process to ensure that the program considers the concerns of the scientists.

10. The Board recommends that the DOE move in a timely way to implement the measures agreed to at the QA workshops.

11. The Board recommends that the QA grading process be improved to provide for greater flexibility in accommodating exploratory research.

Hydrogeology and geochemistry

12. The Board strongly supports the DOE's new policy to improve internal program communication, review, and planning between DOE managers and scientists involved in related disciplines in the program. The DOE should, however, implement a programwide plan and policy for routine external peer review.

13. Recent communication has shown that the DOE is committed to studying the applicability of laboratory measurements in geochemistry and hydrology to site characterization. The Board also is concerned with this applicability and recommends that the DOE continue to address it.

14. The Board believes that the DOE's proposed plan for applying experimental radionuclide sorption results to performance assessment at Yucca Mountain is well conceived. However, inadequate design, documentation, and analysis of many published radionuclide sorption results make it doubtful that they can be used to define conservative sorption behavior. The Board suggests that the DOE model future experimental sorption results using a surface complexation approach. This would lead to a more comprehensive understanding of an explanation for these results, without which we cannot have confidence that such results represent conservative sorption behavior for a particular radionuclide.

15. The Board endorses the DOE's intention to perform some future sorption experiments under unsaturated conditions and to use waters with compositions that might be expected at the site after waste emplacement.

C. Future Board Activities

The Board looks forward to continuing its technical and scientific evaluation of the DOE's civilian nuclear waste management system. Meetings have been scheduled for the coming months on a variety of topics including performance assessment methodologies, site-suitability issues, analogues, and engineered barriers. A second public hearing on transportation issues has been scheduled for August in Denver, Colorado.

The Board continues its interest in the environment and public health aspects of the DOE's repository program, including the environmental standards and implementation procedures that will be applied to it.

Quality assurance issues will continue to be a focus of Board activities. The Board intends to follow up on the progress of efforts to improve the QA process to make it more compatible with the needs of basic research. A new topic for Board inquiry will be the QA procedures for the design of the exploratory shaft facility.

The Board will continue its evaluation of the DOE task force studies, the conceptual design of the repository (including backfilling and sealing), and the preliminary design of the exploratory facility. The Board is interested in hearing about research into the potential effects of thermal loading on the repository and the development of engineered barriers. A complete listing of scheduled activities through November 1991 appears in Appendix B.

Finally, in addition to maintaining contact with Swedish and German experts, the Board will travel to the Whiteshell Nuclear Research Establishment near Pinawa, Manitoba, where efforts are underway to investigate the potential of high-level waste disposal in granitic rock in the Canadian Shield.

D. Observations about Waste Management Activities in Sweden and Germany

Most nations with the technology to generate nuclear power also are exploring how best to dispose of the high-level radioactive waste that results from nuclear power generation. There is international consensus that safe disposal of high-level radioactive waste for thousands of years is technically feasible if a suitable geologic environment is used to isolate the waste. Because other countries are examining issues similar to those being considered in the U.S. nuclear waste disposal program, the potential exists for countries to gain from each other by sharing the information and experience they have gathered.

The Board, as part of its responsibility to evaluate the DOE's radioactive waste disposal program, traveled to Europe in the spring of 1990 to assess the progress that is being made in Sweden and the Federal Republic of Germany (Germany) to develop programs for safely disposing of high-level radioactive waste. In particular, the Board was interested in gathering information on waste management technologies and policies that could be of potential use to the U.S. program.

As a result of site visits and discussions with program personnel and technical experts, the Board made a number of observations. (Background on the individual Swedish and German programs has been provided in Appendix D.)

1. The Swedish and German programs seem to be well conceived and making progress. In both countries, research is taking place underground.

2. As in the United States, interim storage is an integral part of the waste disposal strategy in both Germany and Sweden.

3. Both Sweden and Germany, although to different degrees, are shifting their programs away from reprocessing to direct disposal of spent nuclear fuel.

4. Regulatory criteria used in Germany and Sweden to design and build a repository are based on radiation dose limits to individuals. By contrast, the United States is using regulatory criteria in which specific containment standards must be met. The Swedish and German systems seem to provide them with the flexibility needed to develop the best possible repository design.

5. The Swedes and Germans make less of a distinction than does the United States between the applicant for a repository license and the licensing agency. Although perhaps ensuring a more independent review of a potential repository, the U.S. arrangement may also result in interagency relationships that are sometimes adversarial.

6. In the United States, Germany, and Sweden, nontechnical issues play an important role in some waste management decisions.

7. Although the Swedish, German, and U.S. programs are researching the potential of different geologic media for high-level radioactive waste disposal, a number of topics lend themselves to further information sharing. Examples include

- use of engineered barriers,
- container design and development,
- thermal loading and waste aging,
- grouting and backfilling techniques,
- use of mechanical versus drill-and-blast tunnel-boring methods, and
- assessment methodologies for long-term repository performance.

Introduction

The Nuclear Waste Technical Review Board (the Board) was established by Congress in a 1987 amendment to the Nuclear Waste Policy Act of 1982. The Board was charged with evaluating the technical and scientific validity of activities undertaken by the Department of Energy (DOE) as it designs and develops a system for managing the nation's civilian spent fuel and defense high-level radioactive waste. Specifically, the Board was asked to evaluate DOE activities pertinent to characterizing a site at Yucca Mountain, Nevada, for possible location of a mined geologic repository for permanent disposal of high-level radioactive waste. The Board also was asked to evaluate activities relating to packaging and transport of high-level radioactive waste.

Board activities began in March 1989 with the designation of panels to better address the diversity of technical and scientific topics under consideration by the Board. (See Appendix A for panel breakdown.) The panels hold meetings with representatives of the DOE and other organizations concerned with nuclear waste management issues. The Board has sought to remain apprised of public concerns about the disposal and transport of high-level radioactive waste.

Congress requires the Board to report its findings and recommendations at least twice a year. In its *First Report* (NWTRB, March 1990), the Board outlined the major areas of concern it had identified in its first 10 months of operation. The Board highlighted its long- and short-term plans and made a number of recommendations.

The Board's *Second Report* (NWTRB, November 1990) reviewed Board activities from January to August 1990 and made additional recommendations.

This third report summarizes activities undertaken by the Board from August 1, 1990, through January 31,1991. Due to their timeliness, some activities, while listed here, were discussed in the *Second Report*. Although the Board traveled to Sweden and Germany in May/June 1990, its observations from that trip are discussed in Chapter 3 of this report.

During the past several months, developments have occurred within the DOE Office of Civilian Radioactive Waste Management (OCRWM) program that should produce positive long-term results. First, the management changes made by Dr. John Bartlett earlier in the year seem to have improved the organizational integrity of the OCRWM. Second, the DOE held a series of Strategic Planning Workshops, in December 1990, January 1991, and April 1991, which addressed strategic issues of importance to the OCRWM program. These workshops, which were attended by representatives of many organizations interested in nuclear waste management, will provide input to the DOE's revised Mission Plan. A draft version of the plan will be available for review in June 1991. Third, the Maintenance and Operation contract with TRW, Inc., was signed in March. This effort is designed to enhance the coordination among OCRWM contractors and to improve the integration of the overall program.

The DOE has made a good-faith effort to respond to the recommendations made in Board reports. The DOE's response to the recommendations made in the Board's *First Report* were included in the Appendices of the *Second Report*. Appendix E of this report contains the DOE's response to recommendations made in the Board's *Second Report*. Inclusion of these responses does not necessarily imply Board concurrence.

Chapter 1
Background

A. Introduction

By the year 2000, the United States will have a projected 40,000 metric tons of spent fuel to dispose of. By 2035, after all existing nuclear plants have completed 40 years of operation, there will be approximately 85,000 metric tons. Should the Nuclear Regulatory Commission (NRC) extend the licenses on any of these power plants (for up to 20 years) or if new facilities are licensed, the amounts of spent nuclear fuel that need disposing of will continue to grow. The Department of Energy (DOE) has been assigned by Congress the responsibility of designing and developing a system to manage the disposal of this spent fuel plus approximately 8,000 metric tons of defense high-level waste from reprocessing.

Although high-level radioactive waste has never been disposed of permanently anywhere, there is current worldwide consensus that disposal in a mined geologic repository is the best option for safely containing the waste for thousands of years.

Disposal is a complex undertaking, which poses scientific and technical challenges in diverse areas, including determining the long-term geologic and ecologic character of the site, designing a repository system and assessing the geologic and engineered barriers to radionuclide migration, coping with inevitable uncertainties of the natural and physical phenomena involved in the long-term performance of a repository, setting standards to protect public health and the environment, and managing the entire process, including final decommissioning of a repository.

As with other critical facilities, such as nuclear power plants and dams, licensing standards will be applied to the development of a repository. There is, however, little practical experience upon which to base standards for nuclear waste repositories. Regulations and standards for repository development must be established prior to disposal to ensure the public's safety and the protection of the environment.

B. Existing Framework for Repository Development

A mined geologic repository would consist of natural geologic and engineered barriers that together would isolate high-level radioactive waste from the biosphere for thousands of years. The DOE has been directed by Congress to characterize a site at Yucca Mountain, Nevada, to determine its potential suitability for locating a repository. Should the site prove suitable and meet licensing requirements, a repository would be constructed. Under current plans, such a repository would consist of more than 100 miles of tunnels, excavated approximately 1,100 feet below the surface of the mountain. The repository would cover about two square miles. A waste handling facility would be located nearby.

Many issues must be resolved before the United States can achieve safe, long-term disposal of high-level radioactive waste. The successful completion of this program will require an effort not only on the part of the DOE, but on the part of other federal and state agencies as well. Finally, a waste management system can only succeed if it has broad national support.

C. Board Operation

Congress created the Nuclear Waste Technical Review Board because it recognized the need to establish an independent source of expert advice for Congress and the Secretary of Energy on the technical and scientific aspects of the DOE's work.

As part of its responsibility to review the DOE's program, the Board holds meetings and shares technical information with representatives of the DOE and its contractors, the national laboratories, and other state and federal agencies, as well as with organizations concerned with high-level radioactive waste management issues.

To help the Board gain a better understanding of the public arena in which nuclear waste management technology is being developed, the Board also has solicited the views of the public, the utilities, and environmental organizations. Board members and staff have attended a variety of technical conferences, exchanges, symposia, and workshops. They have participated in field trips to Nevada to examine geologic formations, the ecosystem, the transportation system, the water supply, and other aspects that are pertinent to public health and the environment.

The Board also has visited Swedish and German high-level waste programs to gain insight on similarities and differences in their approach to these issues.

D. Board and Panel Activities from August 1, 1990, to January 31, 1991

The Board addresses issues and makes recommendations in this report that have evolved as a result of activities by the Board and its panels from August 1, 1990, to January 31, 1991. Because of their timeliness, a few activities undertaken during this reporting period were discussed in depth in the *Second Report*. Those activities have been so designated.

During this reporting period, Board members attended 15 Board-sponsored meetings and public hearings. A chronological list of the Board's activities (beginning January 1, 1990, and including those scheduled for the future) is included in Appendix B. A list of those people who have made presentations at Board meetings, panel meetings, and public hearings can be found in Appendix C.

In addition to these Board and panel activities, Dr. Don U. Deere, Board Chairman, provided testimony on behalf of the Board to Congress on October 2, 1990, and March 21, 1991. Dr. Deere's October testimony to the Subcommittee on Nuclear Regulation, Senate Committee on Environment and Public Works, was discussed in the Board's *Second Report*. In March, the Senate Committee on Energy and Natural Resources heard testimony on the progress of the proposed site-characterization activities at the Yucca Mountain site. Dr. Deere's testimony focused on two questions: (1) Is the DOE prepared to initiate site-characterization activities? (2) Is there any reason to disqualify the Yucca Mountain site? A summary of the Dr. Deere's March testimony is presented in Figure 1-1.

Figure 1-1

Testimony Before the Committee on Energy and Natural Resources
United States Senate
March 21, 1991

Dr. Don U. Deere, Chairman, was asked to respond to two questions on behalf of the Board. The questions and the Board's responses follow.

1) Is the DOE prepared to initiate site-characterization activities?

In the Board's view, the DOE is prepared to begin a progression of site-characterization activities as soon as it has gained access to the site. The DOE is ready to expand surface-assessment activities, such as exploratory drilling, trenching, and performing additional environmental and soil studies. While awaiting site access, the DOE has been able to further refine the design of underground facilities (including the layout of openings and exploratory tunnels) and related testing programs.

In its *First and Second Reports to the U.S. Congress and the U.S. Secretary of Energy*, the Board recommended that the DOE's site-characterization program give highest priority to those tests and studies that provide the data necessary for an early determination of site suitability—that is, finding out as soon as possible if there are disqualifying conditions at the site. Recent efforts by the DOE have refocused its site-characterization program along these lines.

The Board is in agreement that the DOE should proceed with its assessment of the Yucca Mountain site.

2) Is there any reason to disqualify the Yucca Mountain site at this time?

Given existing data, there appear to be no *scientific* or *technical* reasons to abandon the site at this time. Until site-characterization studies, particularly subsurface exploration (including boreholes, shafts, and tunnels), have progressed sufficiently, it will be impossible to tell whether or not the site is suitable for repository development. It is conceivable that disqualifying conditions may be identified as the site is being characterized.

It is important to remember that Yucca Mountain has not been chosen as the site for a repository. Rather, it is the single site designated by the Congress for characterization. The Board strongly believes that a candidate site for repository development will have to undergo both surface and underground characterization before its suitability can be adequately evaluated. The critical portion of the data necessary to evaluate the suitability of the Yucca Mountain site has yet to be collected.

Chapter 2
Areas of Inquiry, Recommendations, and Future Board Activities

This chapter is organized into sections according to the major interest areas of the Board's panels. Where the Board's investigation and research have progressed sufficiently since the previous report, recommendations are included. Some of the issues raised here, however, have not yet been examined thoroughly enough by the Board to warrant recommendations at this time. The Board intends to explore such issues further. The Board's planned future activities are summarized at the end of this chapter. (See Appendix B for a list of scheduled meetings.)

Briefly, the major areas of interest covered by the Board's panels can be broken down in the following way:

Structural geology refers to the study of the deformational features of rocks induced by processes such as folding, faulting, and igneous activity. As used in this report, it also includes a study of the processes themselves.

Geoengineering refers to the design, construction, and performance of the exploratory shaft facilities, surface drilling operations, and underground openings at the repository, taking into account the engineering properties of the geologic materials and their spatial variations.

Hydrogeology refers to the study of the geologic aspects of surface and subsurface waters. At the Yucca Mountain site, emphasis is placed on the study of fluid transport through the rock matrix and fractures. Groundwater is considered to be the primary means by which radionuclides (atoms that are radioactive) could be transported from the repository to the accessible environment.

Geochemistry at the Yucca Mountain site is concerned primarily with the potential migration of radionuclides to the accessible environment. Geochemists are studying the chemical and physical properties of the minerals, rocks, and waters that might affect the migration of radionuclides from a repository.

The *engineered barrier system* refers to the waste package, borehole, and repository openings. It includes methods of construction, the near-field host rock, and the backfilling and sealing of all openings. It may be possible to improve confidence in the reliability of the repository to isolate waste from the accessible environment for the long term by relying on geologic barriers *in combination with* a more robust engineered barrier system.

Transportation and systems refers to a system for moving spent nuclear fuel from the more than 100 commercial nuclear reactors located at 70 sites throughout the nation and transporting the high-level radioactive waste from DOE defense facilities to a disposal site. It is not merely the activities associated with packaging spent fuel in a shipping cask and shipping it by highway, rail, or water. Transportation and systems also includes all processes involved before and after the trip—removing spent fuel from its storage facility, loading it into the cask, loading and unloading it at the various handling sites, storing it, and finally emplacing it in a repository.

Environmental issues cover the effects that site-characterization activities and development, operation, and decommissioning of a repository could have on the biosphere, which includes air, water, soil, biologic, cultural, and socioeconomic resources at and downstream, in surface water or groundwater, or downwind from the site for thousands of years.

Public health issues involve potential direct or indirect effects on human health during repository development, operation, and after closure. The possible public health and environmental consequences of the handling and transportation of high-level radioactive waste from points of origin to the repository are also of concern.

Risk and performance analysis refers to the analysis of the long-term performance of a waste repository. Such analysis provides a means for incorporating all scientific and technical aspects into an integrated description of the entire repository system. Performance analysis also can be used to determine which site-characterization studies need to be emphasized or moderated to provide better information on site suitability.

Quality assurance (QA) refers to the oversight strategy that is built into a system to ensure that the system's integrity. Here, QA will ensure the integrity of the technical and scientific studies required for site characterization and licensing. It also will help ensure the integrity of the design, construction, operation, and closure of the repository and its transportation and support systems. Quality control is composed of the auditable specific requirements that must be met to ensure quality in the system.

Recommendations made in this chapter, while addressing activities of a variety of state and federal agencies, are intended to aid the DOE in its efforts to improve the technical work being conducted as part of site characterization at the Yucca Mountain site, and to identify areas for possible improvement in the DOE's transportation program. The Board also identifies areas of future inquiry that may eventually affect the current legislative and regulatory framework.

Section 1 — Structural Geology and Geoengineering

As discussed in the Board's *Second Report* (November 1990), one of the Board's prime concerns has been determining as early as possible whether the site at Yucca Mountain, Nevada, is suitable for locating a permanent repository for disposing of high-level radioactive waste.

In January 1990, the Department of Energy (DOE) began to refocus the Yucca Mountain site-characterization program toward early identification of suitability issues. To facilitate this effort, the DOE established task forces to undertake a series of site-suitability studies. The initial progress of these studies was discussed in the Board's *Second Report* (NWTRB, November 1990). Since that time, the Board has reviewed additional progress made on those studies.

The key studies in the DOE's effort to refocus on early site suitability include (1) evaluating the risks and benefits of excavating exploratory drifts into the Calico Hills unit beneath the proposed repository horizon (CHRBA study); (2) analyzing alternative ESF configurations and construction techniques (ESF alternatives study); and (3) prioritizing scientific testing. In addition, in January 1991 the DOE approved a plan for development and implementation of a methodology and criteria for determining early site suitability. Only the CHRBA study and the ESF alternatives study have been reviewed sufficiently to be discussed in this report.

Although no presentations on the repository conceptual design were made by the DOE during this reporting period, the Board continues to monitor its status. The repository's conceptual design remains of interest because the site-suitability studies have revealed that variations in repository layout and features influence the ensuing results of those studies.

A. Calico Hills Risk / Benefit Analysis (CHRBA) Study

The DOE initiated the CHRBA study in mid-1989 after the Nuclear Regulatory Commission (NRC) staff noted that (1) the need for drifting into the Calico Hills unit had not been established and (2) the potential adverse effects of such drifting on waste isolation had not been evaluated.

To address these concerns, the DOE developed an analytical model of the repository, which includes the Topopah Spring member, engineered barriers, the Calico Hills unit, and the saturated zone. The model was used to estimate radionuclide releases, and the analysis was structured so that a clear definition of the decision criteria could be provided. This framework facilitated the incorporation of available quantitative data and the use of expert judgment, which was provided by a small task force of project specialists.

Early results of the CHRBA study concluded that (1) radionuclide releases from the total system are expected to be at least 1,000 times less than the threshold level used in the probabilistic Environmental Protection Agency (EPA) Standard 40 CFR 191, and (2) excavation and testing in the Calico Hills unit would not likely change this outcome. The CHRBA study concluded further that the saturated zone of the Calico Hills unit and the Prow Pass member would contribute significantly to waste isolation. Test plans and strategies should be reexamined to ensure that the saturated zone will be evaluated adequately during site-characterization.

The early conclusions of the CHRBA study resulted in part from the method used to perform the analysis. This "value of information approach" combined geotechnical inputs, cost estimates, and value inputs to produce a total cost/value for each strategy. The findings concluded that excavating and testing in the Calico Hills unit would not be particularly beneficial because the information gained was not likely to change the predicted outcome—that is, that radionuclide releases would be well within the probabilistic EPA Standard 40 CFR 191.

However, the DOE reassessed these early findings using a multiattribute utility analysis and ranked the alternative strategies according to five attributes.

The DOE has concluded from this additional analysis that extensive excavation in the Calico Hills unit *would* provide a net benefit when considering (1) possible postclosure risks, (2) degree of scientific confidence in testing, (3) the potential for regulatory delay, (4) variations in program cost, and (5) the potential for phasing the tests.

The "preferred" exploration strategy calls for excavating 19,000 feet of drifts to obtain spatial data across the geologic block and crossing all of the faults associated with Yucca Mountain. Including the saturated zone of the Calico Hills unit and the Prow Pass member in the 5-kilometer, horizontal flow path to the accessible environment was a special feature of the CHRBA model that contributed considerably to the low estimates for radionuclide release rate.

B. Exploratory Shaft Facility (ESF) Alternatives Study

The ESF alternatives study is the linchpin of the studies to assess early site suitability. Its purpose is to evaluate and systematically select a preferred alternative for the configuration and construction of the ESF. To accomplish this, the DOE identified a broad range of features, such as shaft and drift size, shape, and orientation, plus a number of excavation techniques. The DOE came up with 17 proposed options, each with a different set of features. Then, each of the 17 options was modified to reflect the preferred underground drifting strategy for exploring the Calico Hills unit identified in the CHRBA study. Seventeen additional options were thus defined, identical to the original 17, but with early access to and early testing of the Calico Hills unit. The original 17 options reflect an attempt to obtain all data identified in the DOE Site Characterization Plan (SCP) (U.S. DOE, December 1988) using a systematic method to proceed from the surface to the Topopah Spring member to the Calico Hills unit. The additional 17 options provide a second strategy to proceed as quickly as possible from the surface to the Calico Hills unit to identify potential evidence of site unsuitability. Except for those tests for which data would be lost irretrievably, testing in accesses (i.e., shafts, drifts, and ramps) would be deferred until excavation of the ESF had been completed. Four of the thirty-four options included a new conceptual repository design.

A prioritization strategy for early testing also was implemented to identify potential evidence of site unsuitability.

Seven expert technical panels were used by the DOE to judge the following aspects of the 34 options:

- postclosure health and safety
- preclosure radiological health and safety
- preclosure nonradiological health and safety
- environmental effects
- socioeconomic effects
- cost and schedule implications
- characterization testing

In addition to the technical panels, a panel to address the likelihood of regulatory approval and a management panel to evaluate the issue of overall program viability were used.

The study was essentially concluded in early December 1990, and the Yucca Mountain Project Office recommended three options to DOE headquarters. The first option features access from the surface by inclined drifts with no shafts. The second option provides access from the surface by inclined drifts but features a shaft between the repository horizon and the Calico Hills exploratory drifts. The third option features an inclined drift and a shaft for access from the surface to the repository horizon, as well as a shaft between the repository horizon and the Calico Hills exploratory drifts.

All three options include the early Calico Hills access feature, which offers a schedule savings of approximately one year for completing site characterization; multiple crossings of faults; the use of mechanical excavation techniques; the use of ramps for subsurface access, drifting, and testing; and flexibility in testing and exploration. The Board had previously considered all these features to have significant merit. The three options did not include the new conceptual repository design. A final optimization and selection of a preferred ESF option is being conducted by the DOE, and once an option has been identified, the ESF will proceed into preliminary design.

The expert panel evaluations of the ESF alternatives revealed little apparent difference among the candidate ESF options, and the regulatory approval and program viability panels provided the differentiation needed to establish a clear ranking of the options. The Board continues to stress the need to solicit independent technical judgment early in the development of analytical models, especially in defining rational sets of alternatives to be evaluated by decision-aiding techniques. This would have been particularly appropriate to the ESF alternatives study. The Board feels that more incisive technical judgment early in the study (e.g., by initially defining a more limited and representative set of options to be evaluated) could have reduced the impact of input from the management panel in the final phase of the study.

The Board continues to stress the need for a rigorous evaluation of the preliminary results of the studies. This can be achieved by performing iterations to determine the sensitivity of the results of a given analysis to (1) variations in the alternatives considered, (2) variations in the quantitative input parameters, and (3) substitutions on the expert panels. The CHRBA study illustrated the value of performing initial iterations to demonstrate the sensitivity of the analysis to the assumptions made in formulating the analysis. The CHRBA study indicated that the early analysis was not sensitive to the values of testing.

If an iteration had been performed in the ESF alternatives study subsequent to the sensitivity studies, an improved differentiation among the features of the leading options might have resulted. Consequently, the impact of nontechnical input from the program viability and regulatory approval judgments might have been reduced appreciably.

The Board notes that the most important factor influencing the results of study efforts that employ decision-aiding techniques is the knowledge and experience of the individuals on the various expert panels. Subjective assessments and estimates of technical risk, cost, and schedule for the design and construction of underground facilities require individuals with high degrees of current experience and knowledge. The Board suggests that the DOE consider developing and documenting an explicit rationale and process for the selection of experts. National professional organizations such as the American Society of Civil Engineers, the U.S. National Committee on Tunneling Technology, or the American Underground Space Association could be asked to provide lists of experts with specialized skills in various aspects of the design and construction of underground facilities.

C. Repository Design

As mentioned above, a subtle but discriminating variable used in the ESF alternatives study was the repository conceptual design. Rather than using the SCP version of the repository as the universal, or baseline, design in all options, 4 of the 34 options used a repository concept developed late in 1989. This new conceptual design included changes to the SCP version resulting from changing technology and a better understanding of Yucca Mountain. The new conceptual design assumed excavating a four-block array of drifts at different levels to avoid excessive slopes, avoiding the placement of waste canisters in close proximity to the Ghost Dance Fault, and using mechanical excavation techniques (i.e., tunnel-boring machines). If program viability and regulatory approval judgments had not dominated, the most favored option would have been one of the four using the new repository conceptual design. The Board wonders if these options ranked high (technically) because they incorporated the new repository conceptual design or because of favorable features of the associated ESF configuration.

The Board believes that the technical rationale and conceptual design of the repository, particularly with regard to thermal loading, have not progressed to the same level of definition as that of the ESF. Assumptions have been made about the characteristics and configuration of the repository during the ESF alternatives study that may be shown to be less than valid in the future. This has been noted by NRC staff in their draft technical position paper on the

ESF alternatives study (Nuclear Regulatory Commission, 1990) in which they state that the basis for the major design features of the repository should be clearly documented to provide a baseline against which to judge alternative ESF configurations.

D. Conclusions

CHRBA Study

1. The DOE's results from the CHRBA study show that (a) extensive exploratory drifting and testing in the Calico Hills unit will provide a net benefit, and (b) the potential adverse effects of such drifting on waste isolation do not appear to be significant.

2. The DOE's results show that the saturated zone of the Calico Hills unit and the Prow Pass member in the 5-kilometer, horizontal flow path to the accessible environment contributes considerably to the low estimates for radionuclide release rate.

3. The preferred exploration strategy for the Calico Hills unit was found to be extensive drifting (around 19,000 feet) to obtain spatial data across the Yucca Mountain block and to cross fault zones.

ESF Alternatives Study

4. The Yucca Mountain Project Office recommended the three highest-ranked options to DOE headquarters in December 1990. All three options contain either one or two inclined access drifts (ramps) and provide for early access to the Calico Hills unit with a projected schedule savings of one year.

5. Other meritorious features of the selected options include provisions for multiple crossings of faults, the use of mechanical excavation techniques, and flexibility in exploration and testing. Two of the options have either one or two shafts.

6. Final selection and optimization of a preferred ESF option are being conducted by the DOE and will continue into the preliminary design phase.

7. The Board believes the study could have been done more efficiently by initially defining a more limited set of options, by greater use of external technical experts, and by conducting iterative studies of the preliminary results to determine their sensitivity to input variables. The Board concludes, however, that the study results are allowing the program to move forward on a sound technical basis.

Repository Design

8. In the ESF alternatives study, four options made use of a recently developed repository conceptual layout. This layout includes using mechanical excavation techniques, placing a four-block array of drifts at different levels to avoid excessive slopes, and avoiding waste placement near the Ghost Dance Fault. The Board concludes that such a layout contains many favorable features that should be considered for the repository conceptual design.

9. At present, an imbalance exists between the design level of the ESF and that of the repository. The Board concludes that the conceptual repository design should be emphasized during the ESF design phase. Different geometric layouts as well as thermal-loading alternatives should be explored.

Although considerable progress has been made over the course of the studies, the Board looks forward to reviewing the ESF preliminary design and additional efforts to define the repository conceptual design.

E. Recommendations

1. The DOE should reexamine its test plans to ensure that the saturated zone of the Calico Hills unit and Prow Pass member will be adequately evaluated—considering its appreciable contribution to waste isolation as determined in the CHRBA study.

2. The DOE should continue with the preliminary design of the ESF on the basis of the selected and optimized version of the three highest-ranked options from the ESF alternatives study.

3. The DOE should continue with repository conceptual design throughout the design phases for the ESF. Different geometric layouts and thermal-loading alternatives for the repository should be explored.

Section 2 — Engineered Barrier System

Since March 1990, the Board has sought to broaden its understanding of the repository's design and of the Department of Energy's (DOE) current program to develop an engineered barrier system. The Board thinks it should be possible to reduce overall uncertainty about a repository's long-term performance by relying on geologic barriers *in combination with* a more robust engineered barrier system designed to isolate radioactive waste for thousands of years.

According to 10 CFR 60.2, an engineered barrier system consists of the waste package (waste form, waste canister, canister filling material, and materials immediately surrounding the canister) and the underground facility (i.e., the underground structure including openings and backfill materials).

In January 1990, Board members and staff presented a series of questions to the DOE staff. These questions, which were discussed in the *Second Report* (NWTRB, November 1990), are paraphrased below. It was the Board's belief that the DOE had not given enough consideration to the possibility of developing and incorporating a long-lived waste package into its engineered barrier system design. Such a package might be designed with the capability of retaining radionuclides for several thousand years.

The reason why the DOE has not put more effort into waste package development may be related to its interpretation of the Nuclear Regulatory Commission's (NRC) 10 CFR 60. On several occasions, DOE staff had indicated to Board members that for the purposes of performance assessment calculations, the waste package did not contribute to the retention of the radionuclides beyond 300 to 1,000 years. The DOE also assumed that it could not obtain credit for a waste package lasting longer than 1,000 years. As a result of this interpretation, the DOE's program has been narrowly focused on meeting the 300- to 1,000-year minimum containment specification, rather than on considering an approach such as that proposed in the Swedish report, KBS 3 (KBS 1983). The goal of Swedish efforts to develop a waste package focuses on complete containment of radioactive materials for periods exceeding 100,000 years.

A recent NRC staff position paper (Nuclear Regulatory Commission, Clarification, 1990) clarified what was meant by "minimum" containment time.* NRC staff also have stated that it is possible to consider the protective aspects of other materials included in the waste package.

The following questions continue to reflect the fundamental thrust of the Board's ongoing inquiries into the DOE's waste package program.

1. Is it possible to develop an engineered barrier system that can be shown to have a reasonable degree of assurance of isolating radioactive wastes for periods of time approaching or exceeding 10,000 years?

2. Would the likelihood of attaining a barrier system lifetime of 10,000 years be enhanced by modifying any disposal conditions or by altering the characteristics of the waste materials, such as reducing their thermal output?

Although the above questions have not been explicitly addressed by the DOE, the Board has been briefed by DOE staff and contractors on the studies on corrosion performance of vitrified glass waste and spent fuel. The following discussion addresses those studies.

* Recently, the NRC issued a clarification of section 10 CFR 60.113(a)(1)(ii)(A). That section specifies that the period of time over which the waste material must be substantially contained in the waste package is at a minimum between 300 and 1,000 years. The NRC has stated in its staff position paper that given adequate supporting data, it would be possible to assume containment for periods of time well beyond this minimum specification or requirement.

A. Waste Package Program Funding

The Board has gathered information on several components of the DOE's waste package program: (1) the proposed waste package plan, (2) the defense waste form, (3) the characterization of the expected spent fuel inventory, and (4) the corrosion of uranium dioxide in both irradiated and unirradiated conditions. In addition, the DOE management personnel discussed programmatic prioritization in general and how it fits into the funding of waste package studies.

Approximate funding levels for the waste package program for fiscal years 1989 and 1990 were $13 million and $10.9 million, respectively. The funding level for fiscal year 1991 is $4.7 million. Further dramatic reduction is likely for fiscal year 1992 funding. This trend of reduced expenditures reflects a DOE management decision to ensure that the near-term studies related to site characterization can be implemented as soon as the State of Nevada issues site-investigation permits. As a consequence, the funding of studies related to waste package materials and the corrosion performance of the waste forms has received less emphasis.

The Board is concerned that inadequate and unpredictable funding will endanger the continuity of a rational, long-term experimental program to develop an adequate range of design alternatives for key elements of the engineered barrier system.

B. Waste Package Plan

Although the DOE waste package plan was developed to provide an organized approach to the design of a waste package, the proposed plan involves only a portion of the elements that might be a part of the overall engineered barrier system. For example, the current plan does not adequately consider filler materials within the waste package or the use of specific backfill materials to modify the environment around the emplaced package.

The Board believes the narrowness of the DOE's proposed waste package studies and budgets reflect a lack of appreciation for the many advantages of a well-designed, long-lived engineered barrier system, including increased public confidence in the safety of a high-level radioactive waste repository.

C. Defense Waste Form Studies

Glass has been chosen as the material into which liquid wastes, extracted during the reprocessing of irradiated fuel from the defense program, will be placed prior to disposal. The DOE has built two plants for converting liquid reprocessing wastes into vitrified glass logs. One facility is located at the Savannah River Plant; the other facility is in West Valley, New York. Neither is processing radioactive material now, but both are scheduled to do so in the next two to three years.

The basic process for producing the glass was developed at the Pacific Northwest Laboratory. It is similar to that used commercially in France and elsewhere. A moist sludge containing the radioactive materials is fed into a resistively heated bath of molten glass. Glass-forming additives are provided, and the bath is tapped periodically to maintain the proper level of melt in the furnace. As it is drained from the furnace, the glass is poured into cylindrical stainless steel containers. After the glass is solidified, the stainless steel containers are capped and welded shut, thus forming a waste package. Because of their relatively long, cylindrical shape, these packages are referred to as "logs."

The actual composition of the glass produced is not measured by chemical analysis of melt samples, but is inferred to be "in the correct range" if the rate of aqueous dissolution of grab samples by the so-called "MCC-1" (laboratory) test is equal to, or less than, one gram per square meter per day. It is not clear whether the MCC-1 test is recognized by external organizations such as the American Society for Testing Materials. It also is not clear what the status of this test is with respect to the quality assurance program.

To ensure product uniformity and quality, it would be desirable to establish an optimum range for glass composition that can be monitored readily during glass-making operations. This also would help avoid the delays inherent in chemical dissolution testing prior to approval. For example, metallurgical organizations regularly monitor metal melts using on-line, x-ray analysis (with approved comparison standards) as the basis for controlling metal composition prior to pouring metal from the holding furnace.

Glass-characterization studies focused on composition, corrosion performance, and corrosion models. The studies demonstrated that corrosion performance (of glass) varies with the base composition of the glass and the physical state (liquid or vapor) of the corrosion medium. Placing the logs in stainless steel canisters, which are then placed inside a long-lived canister, should reduce uncertainties about the release of radionuclides to the biosphere by preventing, or greatly delaying, corrosion of the (enclosed) glass.

D. Spent Fuel Corrosion Performance

The Board reviewed two aspects of the spent fuel corrosion testing program: release of carbon-14 from irradiated cladding and the oxidation and/or dissolution of irradiated or unirradiated uranium dioxide. Results indicate that it is likely that the specification in 40 CFR 191 on release of carbon-14 may be exceeded. As indicated in the *First Report* (NWTRB, March 1990), this specification limit is considered unrealistic when other sources of carbon-14 are considered. In studies of corrosion (dissolution) of glass, testing conditions have a major influence on the rate of attack. All testing conditions described by the DOE appear to simulate a saturated (rather than the unsaturated conditions expected at Yucca Mountain) hydrologic condition. Presumably, the only moisture expected inside an unbreached canister would come from chemically combined water in corrosion products. It should be possible to ascertain the quantity of such water from studies of existing hardware. A robust engineered barrier system should minimize uncertainties about the breaching of canisters and the subsequent dissolution of the waste.

E. Spent Fuel Characterization

The DOE has maintained a program to quantify the volume and summarize the characteristics of the inventory of spent fuel to be disposed of in the repository. This program provides a compilation of the current and (to some degree) projected inventory of spent fuel. The inventory is categorized by reactor type, manufacturer, fuel element configuration, and burn-up, among other characteristics. Currently, projected inventories do not consider the possibility that some operating licenses for reactors may be extended.

On several occasions, DOE personnel or contractors commented on the ambiguities contained in the NRC's regulations. Particular note was made of the NRC's (then-recent) clarification of the minimum containment period requirement in 10 CFR 60. Several other questionable items in Part 60 also were referred to: a quantification of "what constitutes substantially complete containment," the possible contribution to containment by the cladding or other filler materials, and other undefined phrases. Similarly, several comments were made about perceived, unrealistically low limits contained in Table 1 of Environmental Protection Agency (EPA) Standard 40 CFR 191, specifically carbon-14. Based on these comments and prior statements by representatives of the DOE, the Board remains concerned about ambiguities and lack of clarity in parts of the EPA's standards and the NRC's regulations.

F. Conclusions

Canister Materials

1. Topics at a DOE workshop on engineered barriers (which has been scheduled for June 1991) should include (1) consideration of geologic analogues in selecting canister materials and their "engineered" environment, (2) alternative materials, (3) chemical modification of the near field to provide "in-situ" mineralogical barriers and/or to control the oxidizing character of the canister surroundings, (4) consideration of thermal loading on the various recommended materials and procedures, and (5) thermodynamic versus kinetic considerations for predicting the performance of long-lived canisters.

Engineered Barrier System

2. The DOE should assign a higher priority to the development of a more robust engineered barrier system. The effort should be supported with adequate, assured, and continuous funding. Much of the research required to develop such an engineered barrier system can be carried on simultaneously with site-characterization activities.

Regulations

3. The current DOE program appears to have been constrained by (1) the DOE's narrow interpretation of the NRC regulations and (2) the ambiguity associated with the regulations. This matter was dealt with in general terms by the Board in its *Second Report*. A number of points, however, still need clarification, for example, what constitutes "proof of substantially complete containment?"

G. Recommendations

The Board makes the following recommendations:

1. High priority should be assigned to developing a more robust engineered barrier system. A workshop on engineered barriers, which was recommended in the Board's *Second Report* and which has been scheduled for June 18-20 in Denver, Colorado, is a logical first step.

2. The Board recommends that the DOE seek clarification of some NRC regulations. The NRC should be able to provide definitions for terms like "substantially complete containment" and the "proof to be required to demonstrate such containment."

Section 3 — Transportation and Systems

The Board is continuing its efforts to encourage the Department of Energy (DOE) to incorporate the principles of system safety and human factors engineering into the civilian waste management program. System safety and human factors engineering have been of interest to the Board from its very outset and have been the subjects of recommendations in both the Board's *First and Second Reports to the U.S. Congress and the U.S. Secretary of Energy.* Although the DOE has acknowledged that in the past it did not have programs or personnel dedicated to these functions, it responded positively to the Board's earlier comments and recommendations and indicated it would explore the possibilities of incorporating them into its transportation program.

The Board is continuing its efforts to encourage the principals in the waste management system to explore ways of minimizing or reducing the handling of waste during storage and transportation. It is important to look at the waste management problem from a systems perspective to find opportunities for improving overall safety and attain system efficiencies. Minimizing handling was the subject of a recommendation in the Board's *Second Report* (NWTRB, November 1990). The recommendation acknowledges the difficulties involved with attaining significant system efficiencies when responsibilities are divided among different participants (e.g., the DOE, Nuclear Regulatory Commission (NRC), and utilities) with varying incentives. The Board will, however, continue to encourage the cooperation of all involved parties during policy and program development.

Finally, during this period, the Board held the first of a series of public hearings. The Board is interested in obtaining input on the public's concerns about safely transporting high-level waste.

A. Discussions with the DOE

The DOE has described to Board members the actions it has taken or will be taking to respond to transportation-related recommendations made in the Board's *First Report.*

The DOE has begun to incorporate system safety principles into its program. It is in the process of obtaining the services of a system safety consultant to help on the transportation system program plan.

With regard to the discipline of human factors engineering, the DOE itself is adding specific people with human factors training to technical review groups and has directed that human factors considerations be incorporated in operational planning. The DOE also has directed contractors to acquire human factors personnel.

The DOE has reviewed the Management Oversight Risk Tree (MORT), a risk-based planning tool (maintained by EG&G, Idaho), and finds it appropriate for use in operations planning. The DOE will have its consultant explore how MORT can be incorporated into its operational planning process.

The DOE also is documenting (for quality assurance) RADTRAN, a transportation risk-assessment tool. The documentation includes examining the assumptions in the code and providing a basis for them. The documentation is expected to be completed by early 1991. The DOE will begin a peer review of RADTRAN in mid-1991. Among the issues to be examined in the peer review are feasible approaches to validation, simplifying the code, and making RADTRAN more user friendly.

During discussions on safeguards, the DOE discussed results of four studies of (postulated) "worst case" sabotage events. The first two studies relied on a theoretical model for the release of radioactivity given a breach; the latter studies relied on actual release data from experiments. These assessments were performed in the late seventies and early eighties. The magnitude of release was the principal difference in input parameters between the earlier and later studies. The dispersal model used, given a release, was the same in all cases. The results were very different. The adverse consequences in the later studies were substantially lower than those in the earlier ones. The disparity was of such magnitude that the Board suggests that the DOE prepare a paper that explains the large differences.

It is the Board's view that technologies and system designs that minimize the handling of spent fuel should be given high priority. Indeed, the Board made such a recommendation in its *Second Report*. Some of the present concepts could involve the placement and replacement of fuel into canisters, casks, or containers several times from initial removal from the reactor spent fuel pool to final disposal. The desirability of minimizing handling becomes apparent when such potential multiple handlings are added to the expected increase in shipment volumes. When the number of avoidable procedures is minimized, system operations become simpler and more efficient, and safety is enhanced. As handling is reduced, the opportunity for accidents is reduced. Worker exposure to radiation is similarly reduced.

The DOE has sponsored studies in the past on two different cask concepts: the dual-purpose cask, a cask useable for both storage and transportation, and the universal cask, a concept that adds final waste emplacement capability to the dual-purpose cask functions. The DOE concluded that although the dual-purpose cask deserves further study, the universal cask may be impractical.

The difficulty with the universal cask concept arises from the fact that it must be licensed as a transport, storage, and waste container under different regulatory criteria. Licensing as a waste container is tied to the licensing of the repository (10 CFR 60). If the container is not deployed until repository licensing, then its utility as a storage cask may be significantly diminished since the need for dry storage may arise much earlier than repository licensing. If it is used as a storage cask before it is licensed as a waste package, then there is risk that licensing under Part 60 may not be granted without substantial modifications to the cask.

The DOE believes that with respect to competing technologies, it should not deprive suppliers of the opportunity to sell their systems or cause unreasonable favor to one system over another. In addition to the single-, dual-, and universal-cask concepts, other viable options exist. The advantages and disadvantages of these and other options should be evaluated using a systems engineering approach.

The Board is mindful of the fact that the so-called "waste management system" is not a monolith under the control of a single central manager, but consists of distinct players, with divided responsibilities and different incentives. The DOE must be responsive to its legislated mandate; the utilities, on the other hand, have obligations to their stockholders and, through the public utility commissions, to their ratepayers. The NRC, because of its regulatory responsibilities, is the one participant that has some purview over the entire process.

Divided responsibilities should not preclude systematic examination of potentially promising concepts. Implementing a promising system concept may require the resolution of regulatory and possibly complex institutional issues. The Board believes that the first step should be to determine "what is promising." Then, for those promising concepts, one can begin identifying potential regulatory and institutional difficulties. For these reasons, the Board proposed that the DOE hold a workshop on minimizing the handling of spent fuel. The DOE has agreed to consider doing that.

B. Public Hearings

Public hearings, which were held for the first time during this reporting period, elicited a general concern about the safety of transporting spent fuel. Witnesses (see Appendix C for listing) mentioned a diversity of issues. At least one witness testified that the level of concern about transporting waste exceeds that of the safety of the repository, should Yucca Mountain become the repository. Some participants representing rural Nevada pointed to the need to consider all factors that contribute to overall risk when making routing decisions. Population concentration is one factor; road quality and emergency response capability are among the others.

Several witnesses, especially those with responsibilities in planning, voiced concerns that decisions about routing and mode should be made early enough to permit various levels of government to perform the requisite planning. The Board is sympathetic to the fact that various steps in the planning process have to occur in a timely fashion.

Some participants pointed to the need for federal assistance to ensure that adequate inspection and enforcement of transportation standards. Others were concerned about the need to develop coordinated state and local training programs for emergency planning and response and of the need for adequate and predictable funding. The Board recognizes that the states play a major role in inspection and enforcement and that state and local governments have traditionally borne the principal burden for emergency response. The Congress addressed this need in the Nuclear Waste Policy Amendments Act of 1987 by requiring the DOE to provide assistance for training.

Some witnesses argued that risk analyses should consider perceived risk. Risks and technical components of risk analysis, including the quality of transportation casks, should be explained and demonstrated so the layperson can understand them. The Board endorses the goal of communicating transportation risks to the public in more understandable language.

A number of participants raised concerns about the structural integrity of transport casks and how they might perform both during normal transport operations as well as during accidents. Except for the rail industry, most participants did not question the adequacy of the NRC's standards for accident conditions. Instead, the public was more concerned about the possibility of human error in the design, manufacture, and operation of the cask fleet. The Board has stressed the importance of human factors engineering and has pressed for its inclusion in the waste management system.

Another kind of cask integrity issue that was raised is whether there should be full-scale testing of casks. This is an area the Board intends to explore in the future.

Other witness testimony pertained to "systems" issues, such as the following:

- The DOE needs to revise its Mission Plan to incorporate the changes that have occurred in the DOE program as well as to ensure that the various programmatic assumptions about the system are included (e.g., whether or not there is a monitored retrievable storage facility in the waste management system).

- There is a need for sensitivity analyses about the effects of these assumptions (e.g., how deployment of dual-purpose casks affects system performance).

- The DOE should more clearly define the storage/transportation system before proceeding with a from-reactor cask development program.

- The DOE should assess the concept for a dual-purpose cask as a system-optimizing tool. As indicated above, the Board has stressed the systems view and the need to explore various ways to minimize waste handling.

One witness pointed out that the transportation program and the impending shipments associated with the Waste Isolation Pilot Plant (WIPP) present analogies to the civilian waste transportation program. The need exists to coordinate these programs and to standardize DOE policies and procedures. From one of the written submissions for the record, the Board has been made aware of efforts of the Western Governors' Association Working Group on Nuclear Waste to enhance the safety of the WIPP transportation program. While the WIPP program is outside the Board's purview, the Board recognizes the potential value of WIPP as predecessor to the civilian program. Therefore, the Board intends to explore, in the near future, ways that the civilian spent fuel transportation program might benefit from the WIPP transportation experience.

Some of the testimony heard at public hearings addressed socioeconomic issues. One witness representing a local government urged the Board to establish a socioeconomic presence because, in the opinion of this offeror, the waste management program would have significant socioeconomic effects, and he argued that such considerations are technical.

There are a number of other issues that reflect deeply felt concerns on the part of the witnesses who presented them, but which the Board believes to be outside of its scope as a body of technical experts. They, nonetheless, increased the Board's appreciation for the importance of concerns to various constituencies and citizens. Some of these issues include (1) the importance, to a local government, of being designated an "affected" county to receive funds for conducting monitoring and planning studies; (2) the independence that a locality has in defining these studies for itself; (3) the effects of an increased level of transport activity on the underlying transportation system; and (4) how that transportation might violate the sanctity of Indian lands and the terms of treaties that relate to their use.

C. Conclusions

1. The Board encourages the DOE to continue its efforts to incorporate system safety and human factors engineering principles into its program.

2. The transportation of high-level radioactive waste is, and is perceived by the public to be, an activity of high safety concern. The principals in the waste management system need to address these concerns by taking steps that improve overall safety and that enhance public confidence.

3. There is concern that the relationships among transportation, storage, and disposal functions are not being adequately considered in the development of system concepts. For example, alternative transport cask configurations need to be considered in an integrated framework that includes different options for dry storage and for receiving-station technologies. The concern is that some DOE projects may be proceeding without an adequate consideration of their relationships to the rest of the waste management program. A broader view of the system may yield more optimal outcomes in safety and system efficiencies.

D. Recommendation

A workshop should be scheduled on ways to minimize the handling of waste in the life-cycle process. The workshop should address the interactions among the major system components — storage, transportation, and disposal. The scope should include potential technologies, possible regulatory impediments, and institutional incentives and barriers to such an integrated system.

Section 4 — Environment and Public Health

For the past year and a half, the Board has reviewed those aspects of the Department of Energy's (DOE) program that could potentially affect the environment and the public health. In its initial report (NWTRB, March 1990), the Board commented on the DOE's environmental program as defined in its report, *Environmental Program Overview*, (DOE, *Overview*, December 1988). As a result of these comments, the Board recommended that the DOE develop a systems approach to its Yucca Mountain ecosystem study and improve the coordination among the various aspects of the program. Similarly, the Board proposed recommendations with respect to Environmental Protection Agency's (EPA) Standard 40 CFR 191, which is designed to protect overall public health. These recommendations urged that 40 CFR 191 be revised and clarified and that "more attention be paid to inherent uncertainties and limitations in geologic information and data projected for periods of tens of thousands of years when formulating acceptable and realistic human health and environmental radiation protection standards."

The Board has continued its examination of the DOE's environmental and public health program, including gathering input from a variety of state and local organizations concerned with these issues at the Yucca Mountain site. As a result of these efforts, the Board recommended in its *Second Report* (NWTRB, November 1990) that (1) the DOE continue to include other agencies, local governments, and Native American groups in its studies of public health and the environment; (2) the DOE and the State of Nevada explore the possibility of developing a cooperative environmental program; and (3) all environmental and public health programs be conducted in a manner that assures that all data developed are appropriate for use during the licensing process. In addition to these efforts on the DOE's environmental and public health programs, the Board has continued its evaluation of the regulations that will control repository development. Board members made a presentation to the Nuclear Regulatory Commission's (NRC) Advisory Committee on Nuclear Waste about Board concerns with environmental and public health safety regulations.

Since the Board's *Second Report*, the Panel on Environment & Public Health (E&PH) has focused its attention primarily on two topics: pertinent regulations controlling the effects of the repository on society and programs for protecting the environment.

A. Regulatory Concerns

The panel's analysis of the existing regulation (draft 40 CFR 191) was covered in presentations by Dr. Deere, Chairman of the Board, and Dr. Carter, chair of the Panel on Environment & Public Health, at the National Academy of Sciences Symposium on Radioactive Waste Repository Licensing. The symposium was held in Washington, D.C., on September 17 and 18, 1990. These presentations were followed by letters to NRC Chairman Kenneth Carr and EPA Administrator William Reilly recommending a cooperative effort between these two agencies in restructuring the environmental radiation standards and implementing regulations for repository licensing and operation.

B. Environmental Program Concerns

To gain a better understanding of the public arena in which nuclear waste management technology is being developed, the Board has solicited views from the public and environmental organizations. Testimony at a public hearing and subsequent E&PH Panel meetings held in Reno, Nevada, on October 15 and 16, respectively, came from representatives of Citizens Alert, southern Nevada counties, from various constituencies such as retired teachers in California and Nevada, the Sierra Club, U.S. and Russian Physicians for Social Responsibility, the Western Shoshone Indians, and other citizen groups.

A number of major issues were raised by the public and government representatives, including (1) distrust of the DOE, (2) concern about the political choice to characterize *only* the site at Yucca Mountain, Nevada, (3) Native American concerns about land use, and (4) the fact that the DOE does not consider "stigma effects" in its environmental program.

Representatives of the principal counties in southern Nevada (Clark, Lincoln, and Nye counties) expressed dissatisfaction with the level of federal funding that supports local and community involvement in socioeconomic information- and data-gathering activities. In addition, county representatives said the DOE needs to improve and strengthen programs in education and public information. The DOE's restrictions on payment of Grants-Equal-To-Taxes also was criticized.

C. Conclusions

1. The Board acknowledges the apparent inadequacy of information sharing between the DOE and the public sector. The DOE should consider expanding its program for enhancing the public's understanding of potential risk issues associated with repository development and other waste management activities. Such a program should be comprehensive and address comparative risks from nuclear and non-nuclear activities. Since the DOE has a reduced credibility, special steps may be required to compensate for this handicap. The DOE may want to review the efforts underway in Sweden and Canada to provide an approach to understanding nuclear waste management risks through public dialogue.

2. The environmental standards of the EPA, contained in the draft 40 CFR 191, are under review for re-issue by the EPA. The Board is pleased that the EPA is considering action regarding its standards for managing and disposing of transuranic and high-level radioactive wastes.

3. The NRC has stated that it does not believe that joint, cooperative rulemaking with the EPA would be useful at this time. Therefore, it will not take any action until the EPA has completed revision efforts and re-issues 40 CFR 191. The NRC has recently clarified its position regarding waste package lifetime, which is contained in 10 CFR 60. This clarification is found in the Nuclear Regulatory Commission Staff Position 60-001, July 27, 1990, Washington, D.C.

D. Recommendations

The Board makes the following recommendations:

1. The DOE should consider developing a comprehensive regional program to expand the public's understanding of the potential risks associated with the development of a high-level nuclear waste repository, as well as of other nuclear and non-nuclear activities. Special efforts should be made to develop a dialogue involving non-DOE experts.

2. The EPA and the NRC should be encouraged to modify and clarify 40 CFR 191 and 10 CFR 60, respectively. The regulations should be risk based, fully protective of public health and the environment, but not too prescriptive. In addition to being consistent and mutually compatible, they should be presented in a clear and understandable manner and be applicable to and defensible in the licensing arena. Furthermore, they should reflect current internationally accepted environmental standards and be compatible with the uncertainties intrinsic to long-term geologic processes.

Section 5 — Risk and Performance Analysis

The Board's main interest in the area of risk and performance analysis is in the methodology used to analyze risk and performance. During the past six months, the Board has continued to focus its attention on reviewing the Department of Energy's (DOE) ongoing effort to use this methodology as an aid in programmatic decision making.

In its *Second Report* (NWTRB, November 1990), the Board made recommendations urging the Department of Energy (DOE) to continue the iterative use of decision-aiding techniques in programmatic areas; to continue to develop methods for assessing expert judgment, particularly the incorporation of technical experts outside the DOE and its contractors; and to consider the more extensive use of analogues to support performance assessment. Risk and performance analysis has played an integral role in supporting the DOE's task force activities. What follows is a brief discussion of the DOE task force studies and their use of performance assessment methodologies.

A. DOE Task Force Studies

As part of its efforts to refocus on evaluating the suitability of the site at Yucca Mountain, the DOE established four task forces to study (1) alternative licensing strategies, (2) surface-based testing prioritization, (3) Calico Hills risk/benefit analysis (CHRBA), and (4) evaluation of exploratory shaft facility (ESF) alternatives. The alternative licensing strategies study is only partially complete. The surface-based testing prioritization study has been revised to encompass all testing—surface-based and underground. Initial results of the study were only recently presented to the Board. There have been, however, several presentations to the Board on the results of the CHRBA and ESF alternatives studies. (See discussion of these studies, particularly the ESF alternatives study and recommendations in Section 1 on structural geology and geoengineering at the beginning of this chapter.)

The Board would like to emphasize the need for an ongoing evaluation of these studies and of the final reports when they are issued. An in-depth understanding of the studies may be required to take advantage of many of the insights gained. For example, in the Board's *Second Report* it was mentioned that in the CHRBA study, the potential overall calculated risk to the public posed by the repository would be so low that knowledge of the hydrogeologic characteristics of the Calico Hills unit would have little effect on overall repository performance as measured against the Environmental Protection Agency (EPA) standard. On the basis of sensitivity studies presented to the Board, the single largest factor contributing to this high level of performance (low level of risk) appears to be assumptions made by an expert panel about the saturated zone. However, the validity of conclusions, the rationale behind underlying assumptions, and implications for future DOE activities can best be assessed after a thorough analysis of the written report, which has been issued just recently.

Similarly, as recommended by the Board, the DOE has made some effort to include outside experts in its task force studies. The nature and true extent of outside expert involvement can also be best assessed after an evaluation of the final reports of the studies. The Board is looking forward to the completion of the task force studies and the issuance of written reports.

B. Performance Assessment Methodologies

According to information presented at an Electric Power Research Institute (EPRI) workshop on performance assessment methodology, at least four separate efforts by various groups are aimed at calculating the total system performance of a proposed waste repository. In addition to ongoing internal DOE and national laboratory efforts, others include a DOE-funded study underway at Golder Associates Incorporated; a utility-funded methodology developed by EPRI and the Edison Electric Institute; and an initial demonstration assessment, carried out by staff at the Nuclear Regulatory Commission. Although these efforts have much in common, they exhibit differences in methodology; input models; parameters; and, in some cases, conclusions. Performance assessments can serve both as a means for reevaluating programmatic priorities and for demonstrating regulatory compliance. At some point, the DOE will determine which, if any, of these methodologies it will use to guide its planning and licensing efforts.

To maximize the insights gained from the DOE task force studies, the Board will devote ongoing attention to the studies and to an evaluation of their final reports.

The Board also will keep abreast of the different performance assessment methodologies as they are developed. At some time, it may be appropriate for the Board to assist in their evaluation.

Section 6 — Quality Assurance

Just as it regulates the licensing and operation of nuclear power plants and other types of nuclear facilities, the Nuclear Regulatory Commission (NRC) has established requirements and regulations for the civilian high-level radioactive waste management program currently being developed by the Department of Energy (DOE). One of the NRC requirements involves the implementation of a quality assurance (QA) program as established in NRC 10 CFR 60, Subpart G. This subpart defines QA as comprising "all those planned and systematic actions necessary to provide adequate confidence that the geologic repository and its subsystems or components will perform satisfactorily in service." This requirement applies to "all systems, structures and components important to safety, to design and characterization of barriers important to waste isolation and to activities related thereto."

The DOE is required by the NRC to implement a QA program based on the criteria found in Appendix B of 10 CFR 50 "as applicable," and the criteria are to be "appropriately supplemented by additional criteria as required ..." Because Appendix B was developed for regulating nuclear power plants and fuel reprocessing facilities, the DOE has implemented its repository QA program based on its *interpretation* of the criteria in Appendix B, as they apply to the civilian high-level waste management program. The DOE has implemented its QA program at all levels of its structure, even in the laboratories where basic geologic research is underway. In fact, the DOE's current effort to develop a high-level radioactive waste disposal system has required and will continue to require extensive basic research to gain a clearer understanding of the geology and natural processes pertinent to the siting, operation, and separation of hazardous materials from the accessible environment after closure of a repository.

The Board recognizes that QA is an important regulatory requirement and management function designed to ensure the soundness and integrity of the scientific and technical undertakings in the waste management program. The Board is concerned, however, that the DOE's implementation of a QA program could stifle needs to be sensitive to the special requirements for rigorous and creative exploratory research necessary for repository development.

A. Federal QA Requirements for the Repository Program

The NRC has acknowledged that much of the regulatory language for the QA requirements for the civilian nuclear waste program comes from an established QA program originally developed for siting, designing, constructing, and operating nuclear electricity-generating plants and fuel-handling facilities. The NRC requirements (in 10 CFR 50, Appendix B) are outlined in 18 criteria to which two additional criteria were later added by the DOE, one for computer software and one for scientific investigations.

The NRC believes that a cost-effective and scientifically compatible QA system for repository development is possible within these existing NRC criteria and that there is adequate flexibility in QA for conducting the scientific research necessary for siting, designing, and licensing a high-level radioactive waste repository. Therefore, according to NRC staff, the effort required to amend Appendix B to accommodate specific repository needs would not be cost-effective. The NRC also asserted that the problems encountered in the DOE's initial QA process are not related to the NRC's guidelines. But rather, in addition to meeting its QA requirements, some DOE technical managers had incorporated into their QA process constraining levels of detailed research plans and multitiered reviews that have escalated both the QA program costs and the frustration levels of researchers.

B. DOE Implementation of the QA Requirements

The existing NRC requirements have been interpreted and implemented in language specific to the

DOE program. The QA requirements apply to all aspects of the civilian high-level radioactive waste management program, and implementation is at multiple levels, each appropriate to a different level of activity. There are different requirements for DOE headquarters, the Yucca Mountain Project Office, the U.S. Geological Survey and DOE laboratories, and other contractors.

The DOE acknowledges that it had encountered difficulties implementing its initial QA program design in research and technical areas. One serious problem that arose was the disenchantment felt by researchers (including key scientists, a few of whom left the program) because of what they thought were overly burdensome management and QA constraints.

To identify the causes of concern being generated among researchers, DOE management had already convened a meeting of Headquarters and Yucca Mountain QA managers, technical project officers, and other scientists on August 7, 1990, in Denver, Colorado. Two follow-up meetings also were held, with invited observers from the NRC, the Edison Electric Institute, and the State of Nevada. The following were identified by researchers as major shortcomings in the DOE QA program.

- A lack of flexibility in the QA process stifles effective scientific research.
- The QA requirements placed on the development and use of software may not be appropriate for basic research needs.
- QA data management constraints make it difficult to schedule field research.
- Communication between research participants and DOE's QA oversight staff is lacking.

Other criticisms of the QA program identified by participants at the August 7 meeting include the following.

- The current Yucca Mountain QA program is unsuitable for use by R&D programs.
- The QA program does not adequately apply conventional scientific quality assurance and control practices.
- Overly conservative and detailed baseline requirements lead to overly rigorous, inappropriate, and ineffective implementation.

Participants made the following principal recommendations during the three meetings.

- Establish a technical advisory group to participate with QA personnel and management in QA decision making.
- Establish a forum for technical/QA management exchange.
- Schedule licensing workshops involving the NRC and DOE.
- Ensure that the QA program makes maximum use of normal scientific quality assurance and control processes.
- Develop an appeals process for QA decisions.
- Focus on resolving short-term QA problems related to technical publications, document review, training effectiveness, program flexibility, and document-handling procedures.

As a result of efforts to evaluate its own QA program, the DOE QA management concluded that the fundamental problem was not intrinsic to the QA process. Rather, management argues that the problems resulted from some technical managers melding highly specific (and often unrealistic) performance milestones and planning requirements together with QA requirements. As a consequence, QA auditors found many instances when researchers had departed from detailed plans or milestones, causing multiple levels of reviews to the detriment of the research, the QA program, and the DOE's progress on repository siting and design.

DOE QA management personnel and a representative of the laboratories' QA staff expressed confidence that the problems have been diagnosed and the needed changes are being made to develop an effective and efficient QA process that is compatible with and sensitive to the special needs of the researchers. Initial QA implementation, which mixed QA and management processes, consumed 30 to 35 percent of the scientific effort; the DOE believes this can be reduced to a steady 10 to 15 percent after early problems with QA have been solved.

Comments to Board members from the technical project officers, who sit much closer to the researchers than DOE headquarters and laboratory QA managers, resulted in a mixed message. Technical project officers agree that the DOE now recognizes the existence of a serious problem in the method it used to implement the initial QA process. They also agree that changes in the QA program already underway at the DOE and in participant organizations are generally in the right direction. Despite this, some laboratory technical managers and researchers doubt that existing damage to the research operation can be repaired soon.

C. Nevada's QA Program

The State of Nevada has adopted a QA program so that the data it collects can be used in the NRC's licensing process for repository siting. Its QA procedures do not, however, apply to data and analyses for environment and public health (including socioeconomic issues). For these areas (in lieu of a formal QA process), certification that the "best scientific practices" are followed is the only requirement.

Nevada's QA process has been underway since 1987. With only one full-time person, it seems much simpler than the DOE's. Nevada's present QA concern is chiefly to ensure that the data it gathers for participating in the licensing decision process meet the NRC requirements. It estimates that only 10 to 15 percent of its total effort goes into QA. The state imposes its QA guidelines on its researchers by making those guidelines a stipulated component of all its contracts and subcontracts. Nevada is confident that data generated by its performers will be in full compliance with NRC regulations. Some research participants say they have felt constrained by the state's QA process.

D. Another Perspective on QA: The EPA QA Program

The Board obtained a description of the Environmental Protection Agency's (EPA) formal QA program to gain a perspective of QA implementation at another federal regulatory agency and of a program that has been in place for some time.* The EPA highlighted the following points.

- The EPA QA process is driven by requirements to make the best decisions.
- At the EPA, QA is a management decision-making function that extends from the top down.
- The EPA is especially sensitive to the risks from false positives and false negatives in data and analyses because of the cost and liability associated with decisions based on such errors.
- Many regulatory decisions can be made at the EPA without having to generate new supporting data.
- It is agency policy "to ensure that environmental data collected by the agency are of known and expected quality and adequate for their intended use."

The EPA also appears to have a more systems-oriented approach to determining when additional data are required for a high-quality decision. It does not apply costly QA requirements to all of its studies, but rather only to those that support regulatory decision making. Particular cognizance is taken of who the stakeholders are (i.e., the administration, Congress, the general public, regulated industry, or action groups). In the EPA's view, internal manage-

* The EPA, through EPA Order 5360.1, imposes a QA requirement on all environmental data collected under agency auspices. Implementation specifics, however, are left to the individual major agency programs (e.g., Superfund) to be tailored according to those program's data needs and the nature of the decisions that have to be made. The extent, quality, and level of detail of QA procedures, therefore, vary from one EPA program to another.

ment reviews and oversight will not be seen as punitive or time wasting by investigators if QA is done only when it is essential to the quality of a decision.

Like the NRC and the DOE, the EPA has internal orders (EPA Order 5360.1) that outline roles and responsibilities for carrying out the mandatory agency QA program. The agency also has published regulations on QA such as 40 CFR 30 & 31 and 48 CFR 15. Such requirements are imposed on its contractors through inclusion in the language of grants, contracts, and cooperative agreements.

The EPA QA program has a two-tiered process for management: one at the organizational upper level and one at the program level. At the upper level, a management plan for quality assurance provides the blueprint for quality management process and structure; a review of management systems assures the effectiveness of the QA structure and processes. At the program level, data quality objectives state the standards and goals for the data to be used in decision making. Quality assurance project plans provide the blueprint for achieving data quality objectives as related to various agencies and guidance documents. Technical system audits assess the data collection system. And, finally, audits of data quality provide additional assurance.

E. Conclusions

The DOE's QA program is still in the early stages of implementation, and initial problems and discontent were probably inevitable. The Board believes that the major source of discontent can be attributed to differences between the DOE technical project and QA managers on one hand, and the working scientists on the other. Some specific causes of discontent include the following.

1. The original NRC regulations were designed for application to reactor engineering and hardware rather than natural science research. The high levels of natural variance and consequent large areas of uncertainty that characterize geologic environments require highly flexible research plans. Technical project officers and QA managers initially sought to constrain research plan flexibility.

2. The EPA has learned to limit its detailed QA program to those areas where the acquisition of data is required for specific regulatory decisions. While the DOE system includes a graded QA provision, the current amount of flexibility permitted for exploratory research remains constrained. Basic researchers accepted DOE repository-related research assignments compatible with their basic research interests. But such projects were only remotely related to data needed for repository licensing decisions. The planned DOE revisions in the QA processes may provide for the very different QA requirements for the two kinds of activities.

3. In some cases, DOE technical project managers imposed very high levels of detail on research plans under the rubric of the QA process. These plans were recycled several times and ended up including specific requirements that would not, and often could not, be met in the field or laboratory by the researchers. (This panel conclusion is based on examination of one specific example.) The time and cost of the initial DOE QA process to the technical program was very high, with estimates ranging from 20 to 60 percent for individual research projects.

4. QA auditors, like all good auditors, searched for every departure from stated plans and found numerous departures from some overly detailed research plans that had been forced on the researchers by DOE management.

5. The morale of some of the program's top researchers was strained by mandatory, sometimes unworkable, highly detailed research plans; by high-level DOE questioning of the quality of their past research; and by long delays in approval of manuscripts prepared for peer-reviewed scientific publications. A few of the researchers have left the program.

The DOE QA management believes (and the NRC and most of the technical managers concur) that the DOE now has identified the problems. Working jointly with the technical managers and researchers, the DOE has initiated processes to determine what must be done to work toward more effective, separate QA and technical management programs. Some, but not all, of the scientific research managers in the repository participant group have expressed optimism that the problems are being addressed and will be resolved. Based on a formal meeting with DOE managers and technical project officers, and subsequent contacts with individual researchers, the Board is encouraged by this DOE effort to revise its QA processes and believes that it has the potential of providing a continuing mechanism for maintaining dialogue and improving QA implementation.

F. Recommendations

1. The Board praises the DOE for initiating a two-way process to identify and resolve QA implementation issues that have been identified by DOE management and researchers. The Board concurs with the DOE's QA managers that the QA process should not be coupled with highly detailed management/administrative procedures. The Board recommends that the DOE continue this process to ensure that the program considers the concerns of the scientists.

2. The Board recommends that the DOE move in a timely way to implement the measures agreed to at the QA workshops.

3. The Board recommends that the QA grading process be improved to provide for greater flexibility in accommodating exploratory research.

Section 7 — Hydrogeology and Geochemistry

In its *First Report* to Congress and the Secretary of Energy (March 1990), the Board recommended that the Department of Energy (DOE) organize a workshop on radionuclide sorption to be attended by representatives of the DOE and those contractors involved in the measurement and modeling of such sorption. As the *First Report* stated, the workshop would have two general purposes: "(a) to determine the applicability of available radionuclide sorption data on tuff and models for predicting such adsorption under existing and postclosure conditions at Yucca Mountain and (b) to establish what additional radionuclide sorption research and model development are needed." The *First Report* further suggested that such research and model development "should attempt to demonstrate that quantitative, scientifically defensible predictions of radionuclide adsorption at Yucca Mountain are possible and to show how such measured and predicted adsorption relates to compliance with the radionuclide release rate criteria set forth in 40 CFR 191."

In response to the Board's proposal, the DOE organized and held a radionuclide sorption workshop in Los Alamos, New Mexico, on September 11-12, 1990. The workshop was attended by the DOE and its contractors, by independent researchers from outside the DOE program, staff of the Nuclear Regulatory Commission (NRC) and its contractors, and staff and consultants of the State of Nevada's Nuclear Waste Project Office. Based on oral presentations and discussions held at the workshop, and consequent deliberations among DOE staff, the DOE prepared a draft report entitled 'Evaluation of and Recommendations from Sorption Workshop' (*Sorption Workshop Report*), which was forwarded to the Board on February 13, 1991, (Department of Energy, February 1991). Further discussion of the DOE's future plans, related to the study of radionuclide sorption at Yucca Mountain, was presented as part of a DOE-NRC technical exchange held March 20-21, 1991, in Los Alamos, New Mexico, on "Mineral Stability and Applicability of Laboratory Data to Repository Transport Calculations."

The Board commends the DOE for holding the workshop and for proposing constructive changes in its programs related to radionuclide sorption at Yucca Mountain. The Board largely supports these proposed changes as outlined in the DOE's *Sorption Workshop Report*, and further detailed at the aforementioned DOE-NRC technical exchange. The following discussion examines some of the DOE's proposals for program changes and for future activities, as well as the Board's concerns about those changes and proposals.

A. Program Changes and Future DOE Activities

Improved internal DOE communication, program review, and planning

In its *Sorption Workshop Report*, the DOE outlines a new programwide policy to improve communication between and among the DOE and its contractors. This should significantly increase the efficiency and focus of site-characterization efforts. Monthly conference calls or meetings and internal quarterly meetings or workshops are to be scheduled involving DOE managers and technical personnel working in related scientific areas. Participants will exchange monthly reports and yearly work plans. The Board supports this effort, but also would like the DOE to establish an official policy whereby the program is subject to routine external peer review.

An internal review of the experimental program in radionuclide transport and sorption is ongoing and will produce a DOE report recommending future work. DOE management will use this report to prioritize such work and its funding.

Radionuclide transport issues and performance assessment

The DOE proposes to develop process-level models, both mathematical and conceptual, to assist in the design and interpretation of experimental work related to radionuclide transport. These detailed models will form the basis for developing more simplified models to be used in performance assessment. Formulation of the simplified models will be an outgrowth of sensitivity analyses to identify important processes and eliminate others.

Applicability of experimental study results to conditions at Yucca Mountain

In its *First Report*, the Board expressed concern that available laboratory results often could not be used confidently to describe or predict radionuclide behavior at Yucca Mountain. As part of a related effort, the DOE is now preparing a study plan on field investigations that will examine the significance of differences between laboratory and field aqueous concentrations, and mineralogical and hydrologic parameters.

Processes controlling radionuclide mobility between the waste package and the accessible environment

Several processes can reduce the concentrations of radionuclides should they escape from the engineered barrier system. These processes include dispersion and diffusion (especially in rock matrix), radioactive decay, isotopic exchange, precipitation and coprecipitation in secondary phases, colloid filtration, and sorption. Radionuclide mobility may, however, be enhanced by fracture flow and gas-phase transport (such as of $^{14}CO_2$) and by processes and reactions that inhibit retardation processes.* The latter include colloidal transport, competitive sorption (for example, Ca^{2+} competes with Ra^{2+}), and the formation of radionuclide complexes that will limit precipitation and can prevent sorption (e.g., uranyl carbonate and thorium sulfate complexes inhibit precipitation and are sorbed poorly).

B. The Measurement, Modeling, and Application of Radionuclide Sorption Data

The development and DOE approval of geochemical computer codes

The DOE is working on a geochemical code or codes that can model and predict radionuclide sorption by clays and by zeolites of variable Si / Al content. These models also would consider multiple sorption sites and the effects of temperature.

As a related issue, it was suggested at the sorption workshop that the EQ3/6 geochemical code (Wolery et al., 1990) be enlarged to include more sophisticated sorption models, including surface complexation models. The Board agrees that this would be desirable, but also suggests that for many sorption modeling applications, it would be more efficient and cost-effective if the DOE would approve use of the existing MINTEQA2 geochemical code in the program (Allison et al., 1990). This code, which contains several surface complexation models and is supported by and has been quality-assured by the Environmental Protection Agency (EPA), already has been used in the study of nuclear waste disposal problems (Krupka and Morrey 1985). MINTEQA2 also has been combined with transport codes (Mangold and Tsang 1991).

The DOE strategy for addressing radionuclide sorption as it relates to compliance with the EPA standard

At the DOE-NRC technical exchange, the DOE proposed a strategy for prioritizing its future radionuclide sorption research. Its strategy is based on a report (Oversby 1987) that compares the NRC's permissible release limits for radionuclides from the engineered barrier system (10 CFR 60) with the EPA standard (40 CFR 191) for release of radionuclides to the accessible environment. Based on that comparison, she identifies the radionuclides that would probably need to be most reduced in amount after leaving the engineered barrier system to avoid exceeding the EPA release rates to the accessible envi-

* Please see either the Glossary or the periodic chart at the end of the Glossary for definitions of chemical symbols.

ronment. In roughly decreasing importance, these include Am, Pu, Th, U, Cm, C, Np, Ra, Ni, I, Cs, Sn, Se, Zr, Nb, Tc, and Pd. (See also Domenico et al., 1989.)

The DOE proposes to group the radionuclides of concern by their general sorption behavior. The suggested approach would be in principle highly conservative. For performance assessment, the DOE would adapt distribution coefficients (Kd's) for individual radionuclides measured in experiments in which the least sorption has been found. These experiments would examine the sorption of each radionuclide using possible water compositions at Yucca Mountain selected to ensure minimal sorption of that radionuclide by the least sorbent, important minerals present (presumably feldspars and quartz), and by the least sorbent rocks within individual units from Yucca Mountain. The DOE anticipates that such experiments would show Kd >50 (ml/g) for pure minerals and/or rocks that were poorly sorbing with respect to Am, Cm, Np, Sn, Th, Zr, and possibly Ni and Pu. This Kd corresponds to radionuclide retardation relative to groundwater flow by perhaps 200-500 times and should assure compliance with the EPA release rate. The DOE expects that Cs, Sr, and Pu also would exhibit Kd values greater than 50 in minimum-sorbing rock units, and that the only radionuclides likely to show less retardation (lower Kd's) are U, Np, Tc, I, and C. Given that the anion-forming radionuclides of Tc, I, and C are generally poorly sorbed and in some instances exhibit anion exclusion, the conservative approach is to assume that these radionuclides are transported at least as fast as the groundwater. Of course, ^{14}C as CO_2 gas can travel much faster than the groundwater. Necessary reductions in concentrations of these three radionuclides may have to depend on processes other than sorption. The DOE's analysis suggests a need for further measurement and modeling of U and Np and perhaps Pu sorption to determine whether minimum possible sorption can provide an adequate barrier to the release of these radionuclides.

It is expected that many so-called conservative Kd values will be selected from the published literature. For example, an extensive summary table of retardation coefficients (Rd's) and Kd's for radionuclides sorbed by tuff units from Yucca Mountain is given by Meijer (1990). However, if the lowest (non-zero) Kd's in the table are assumed to represent conservative sorption, the assumption may well be incorrect. This is because the detailed laboratory experimental conditions that controlled the extent of measured sorption, including, for example, the pH and the presence of competing and complexing dissolved species, have not been reported. Nor is it evident that minerals in the rock had been pre-equilibrated with the water used in the sorption experiments before radionuclide sorption was measured (see below). Thus, whether a relatively small tabulated Kd is conservative or not cannot be proven without information on solution speciation, tuff mineralogy, and the state of tuff-water equilibration during the experiments. Furthermore, except for zeolites and smectite clays, Kd values are usually strong functions of pH, because of the pH-dependent changes in surface charge exhibited by oxides and to a less extent by illite clays in the tuff.

In short, the Board suggests that the DOE not depend on published sorption data as a basis for selecting "conservative" Kd values, unless these data have as been properly measured and reported. To be meaningful, Kd values should be provided with sufficiently detailed information on the experimental conditions used to allow a calculation of solution speciation and other system properties, including those of sorbent minerals and rocks. The same arguments apply to the conduct of future DOE sorption experiments intended to define conservative radionuclide sorption. The Board believes that performing sorption experiments in laboratory systems pre-equilibrated with the rock, and sufficiently well characterized to allow parameterization of a surface complexation modeling approach to the data, would help to assure that the sorption process was sufficiently well understood to prove that a result or results were conservative.

The composition of waters used in sorption experiments

Most radionuclide sorption experiments involving Yucca Mountain tuff have been performed in batch tests at high water/rock ratios, using, for example, water from well J-13. In these water-dominated conditions, the water may not have a chance to equilibrate with minerals in the tuff, which continue to dissolve for days to weeks, mostly incongruently (White and Claassen 1979). The precipitation of secondary minerals and the sorption of rock dissolution products obviously cloud the significance of radionuclide sorption experiments that are run in such a system.

Radionuclide sorption from unsaturated- and saturated-zone waters at Yucca Mountain will generally be from systems having very low water/rock ratios. These are rock-dominated systems, in which, given the long water/rock contact times, minerals in the rock will tend to have equilibrated with waters transporting any radionuclides, and from which sorption is taking place. Preliminary information on the compositions of such waters at elevated temperatures, such as might be expected in the thermal zone near the waste package, has been estimated by Lawrence Livermore National Laboratory (LLNL) researchers through experiments and EQ3/6 modeling. They observe that such rock-dominated waters develop a composition that is independent of the original water composition. In its *Sorption Workshop Report*, the DOE proposes to examine radionuclide sorption by tuffs from unsaturated-zone water compositions such as have been reported by Yang et al. (1988, 1990). Sorption would also be studied using tuff water compositions predicted from the experimental and modeling approaches of the LLNL researchers. The Board endorses such an experimental approach.

Unsaturated- versus saturated-tuff sorption experiments

The Board commends the DOE for deciding to run some of its future sorption experiments in unsaturated tuff to confirm that the results of such experiments agree with those obtained under saturated conditions. The DOE also intends to perform some future sorption experiments at intermediate (caisson) scale, as well as in small laboratory column and batch experiments as in the past.

Radionuclide sorption by fracture minerals

At the DOE-NRC technical exchange, the DOE stated that it would assume no credit for sorption of radionuclides in fractures and that all credit for such sorption would be given to minerals in the rock matrix. This assumption further emphasizes the need for the DOE to determine the character and relative importances of fracture and matrix flows at Yucca Mountain from on-site measurements.

C. Conclusions

Program communication

1. The Board commends the DOE for its newly announced policy to improve internal program communication, review, and planning between and among the DOE and its contractors. This policy should significantly increase the efficiency and focus of site-characterization efforts. The Board's only concern is the apparent lack of official DOE policy and procedures for routine external peer review of the DOE's programs.

Applicability of laboratory results

2. In its *First Report*, the Board expressed concern that available laboratory results often could not be used confidently to describe or predict radionuclide behavior at Yucca Mountain. The DOE's decision to perform such future radionuclide sorption experiments in unsaturated tuff, and also at intermediate scale in caissons, should help dispel the Board's concerns. The DOE's on-going preparation of a study plan to examine the significance of differences between laboratory and field aqueous concentrations and mineralogical and hydrologic parameters, further signals the DOE's intent to address this problem.

Strategy for addressing radionuclide sorption as it relates to compliance with the EPA standard

3. The Board generally supports the DOE's planned strategy for evaluating site compliance with the EPA's radionuclide release-rate limits to the accessible environment and the DOE's approach for prioritizing related, future radionuclide sorption research. Inherent in the DOE's planned approach to such sorption research is the intent of selecting conservative sorption distribution coefficients (Kd's) for performance assessment. A conservative Kd for a

particular radionuclide would be one that had been measured using waters from which sorption was minimal onto minerals or tuff units, themselves exhibiting minimal sorption for that radionuclide. The Board is concerned that the inadequate design and documentation of many previous sorption studies precludes the use of their results to confidently prove conservative sorption behavior of a given radionuclide.

Choice of water used in sorption studies

4. The Board approves the DOE's intent to use waters in radionuclide sorption studies that are compositionally similar to those expected in the unsaturated and saturated zones following waste emplacement at Yucca Mountain. Such waters will have rock-dominated compositions, largely independent of their composition prior to contact with Yucca Mountain tuffs.

Radionuclide sorption in fractures versus matrix

5. The DOE has decided that it will assume no credit for radionuclide sorption in fractures and that all credit for such sorption will be assigned to minerals in the rock matrix. This assumption further highlights the DOE's need to make *in-situ* measurements to determine the character and relative importance of fracture and matrix flows at Yucca Mountain.

D. Recommendations

1. The Board strongly supports the DOE's new policy to improve internal program communication, review, and planning between DOE managers and scientists involved in related disciplines in the program. The DOE should, however, implement a programwide plan and policy for routine external peer review.

2. Recent communication has shown that the DOE is committed to studying the applicability of laboratory measurements in geochemistry and hydrology to site characterization. The Board also is concerned with this applicability and recommends that the DOE continue to address it.

3. The Board believes that the DOE's proposed plan for applying experimental radionuclide sorption results to performance assessment at Yucca Mountain is well conceived. However, inadequate design, documentation, and analysis of many published radionuclide sorption results make it doubtful that they can be used to define conservative sorption behavior. The Board suggests that the DOE model future experimental sorption results using a surface complexation approach. This would lead to a more comprehensive understanding of an explanation for these results, without which we cannot have confidence that such results represent conservative sorption behavior for a particular radionuclide.

4. The Board endorses the DOE's intention to perform some future sorption experiments under unsaturated conditions and to use waters with compositions that might be expected at the site after waste emplacement.

Section 8 — Future Board Activities

The Board looks forward to continuing its technical and scientific evaluation of the DOE's Civilian Nuclear Waste Management System. Meetings have been scheduled for the coming months on a variety of topics including performance assessment methodologies, site-suitability issues, analogues, and engineered barriers. A second public hearing on transportation issues has been scheduled for August in Denver, Colorado.

The Board continues its interest in the environment and public health aspects of the DOE's repository program, including the environmental standards and implementation procedures that will be applied to it.

Quality assurance issues will continue to be a focus of the Board. The Board intends to follow up on the progress of efforts to improve the QA process to make it more compatible with the needs of basic research. A new topic for Board inquiry will be the QA procedures for the design of the exploratory shaft facility.

The Board will continue its evaluation of the DOE task force studies, the conceptual design of the repository (including backfilling and sealing), and the preliminary design of the exploratory facility. The Board also is interested in hearing about research into the potential effects of thermal loading on the repository and the development of engineered barriers. A complete listing of scheduled activities appears in Appendix B.

Finally, in addition to maintaining contact with Swedish and German experts, the Board will travel to the Whiteshell Nuclear Research Establishment near Pinawa, Manitoba, where efforts are underway to investigate the potential of high-level waste disposal in granitic rock in the Canadian Shield.

Chapter 3
The German and Swedish Nuclear Waste Disposal Programs — Observations

Most nations with the technology to generate nuclear power also are evaluating how best to dispose of the resulting high-level radioactive waste. International consensus is that safe disposal of high-level radioactive waste* for thousands of years is technically feasible if a suitable geologic environment is used to isolate the waste. The United States, for example, is evaluating the potential of tuff, a rock composed of volcanic ash, to safely contain high-level waste; other countries are considering geologic media such as salt and granite.

Extensive research also is underway in some countries to evaluate the use of long-lived waste packages and other engineered barriers that, together with the geologic environment, could better assure the containment of high-level radioactive waste for thousands of years. Because other countries are examining issues similar to those being considered in the U.S. nuclear waste disposal program, the potential exists for all countries to profit by sharing information and experience.

The Nuclear Waste Technical Review Board (the Board), as part of its efforts to evaluate the Department of Energy's (DOE) radioactive waste disposal program, traveled to Europe in the spring of 1990 to assess the progress that is being made in Sweden and the Federal Republic of Germany (Germany) to develop programs for safely disposing of high-level radioactive waste. The Board wanted the opportunity to visit research sites and to meet with professionals who are involved in other waste programs. In particular, the Board was interested in gathering information on waste management technologies and policies that could be of potential use to the U.S. program.

The Board chose Sweden and the Federal Republic of Germany (at that time western Germany) because both countries, like the U.S. program, have well-developed R&D programs focused on deep geologic disposal. Time did not allow visits to other European countries.

From May 27 to 29, 1990, the Board visited two sites in Sweden: the Swedish Final Repository (SFR) for low- and intermediate-level radioactive waste at Fors-mark and the Stripa Mine Research Project west of Stockholm. The Board then traveled to Germany, where it spent May 30 to June 1, 1990, at the Gorleben underground interim storage facility near Gartow and the Asse salt mine near Braunschweig, an underground facility for R&D of methodologies for disposing of high-level radioactive waste.

Although time constraints limited the number of facilities the Board was able to visit, the host countries made an effort to bring Board members together with representatives from most of the major

* Sweden and Germany use the term "high-level waste" somewhat differently than does the United States. See Appendix D and the Glossary for detailed definitions.

governmental or private institutions involved in disposing of nuclear waste in their respective countries.

The Board appreciated the opportunity to visit with experts and review the progress being made in other countries in solving high-level waste management issues. Since its trip to Sweden and Germany, the Board has remained in contact with its counterpart in Sweden, the Statens Kärnsbränsle Nämnd (SKN). The Board and the SKN intend to continue to exchange information on issues of mutual interest.

A. Observations

As a result of site visits and discussions with program personnel and technical experts, the Board made a number of useful observations. Seven of them are outlined briefly below. Each observation is accompanied by a short explanatory discussion. Summaries of the individual Swedish and German programs have been provided in Appendix D.

When evaluating the progress that has been made in the Swedish and German waste programs, the following should be kept in mind. Sweden and Germany will have relatively small amounts of spent fuel compared to the amounts being generated in the United States. Projections for the year 2000 are approximately 8,000 and 9,000 metric tons, respectively, compared to at least 40,000 metric tons in the U.S. (Leigh and Mitchell 1990). The amount of waste that needs to be disposed of and the geographic areas available for possible repository location affect the components of these respective programs (e.g., program schedule, location, and transportation system design).

The regulatory frameworks in Sweden and Germany for licensing a repository are different from that in the United States. In Germany, for example, final licensing authority rests with the state, not the federal government.

The political and institutional frameworks for managing waste in Sweden and Germany differ from those in the United States. Responsibilities have been assigned under a different management configuration. In addition, the private sectors are more involved in developing and implementing their respective waste management programs in Sweden and Germany than in the United States. Finally, the authority assigned to state and local governments varies from one country to the next.

Observation: The Swedish and German programs seem to be well conceived and making progress.

Although politics (especially in Germany since reunification in October 1990) or unforseen technical issues may change their current waste disposal plans, both countries have established specific R&D programs for disposing of high-level radioactive waste. In addition, both countries are performing research underground and are collecting other data that will enhance their disposal programs.

Swedish authorities plan to begin construction of a repository in granite by the year 2010. Since 1977, Sweden has examined 14 potential locations throughout the country for repository development. By 1996, characterization of two sites selected as finalists is scheduled to begin, with final selection of one site by 2003. At the same time, SKB, the Swedish company responsible for the development and operation of the repository, has developed a number of repository concepts and is working underground, studying the properties of granite, the pattern of fracture zones, and the physical and chemical conditions of the groundwater. Investigations are underway in and adjacent to rock formations that could be suitable to host all the spent fuel (7,800 metric tons) that will be generated in Sweden by the year 2010. A critique of the R&D program in 1989 recommended that work focus on constructing a small-scale repository before a full-scale repository is built.

In Germany, current plans call for a repository to be licensed and built by the year 2008, possibly at Gorleben, location of a large salt dome. In the interim, extensive underground research is in progress at Gorleben and at the Asse II Research Mine to determine the best method for disposing of high-level radioactive waste in salt.

Observation: As in the United States, interim storage is an integral part of the waste disposal strategy in both Germany and Sweden.

Literature provided from both countries indicates that interim storage has been part of the strategy for spent fuel disposal since the initiation of their respective programs. In Germany, storage of spent fuel in water-filled pools is provided at most reactors for three to ten years, but some reactors with less capacity use dry storage in dual-purpose, nodular, cast iron casks, similar to those used at the Virginia Electric Power Company's Surry plant. Interim, away-from-reactor storage at Gorleben and/or Ahaus also is planned but has not been implemented to date. Facilities at both Asse and Gorleben have a capacity for approximately 420 canisters or a maximum of 1,500 metric tons of uranium.

In Sweden, centralized interim storage takes place in pools at the CLAB facility. The facility was designed to hold spent fuel from all Swedish nuclear power plants from the time it leaves the pools at the nuclear power plants until it is removed for final disposal. At the time CLAB was designed (1976), the technology for storing waste in dry casks was in its infancy and not expected to be licensable. Consequently, dry-cask storage was not considered seriously. When spent fuel is discharged from the reactor, it is stored on-site for approximately one year in a pool. It then is shipped to CLAB. Although the primary reason for interim storage in Sweden is to provide a central place to age the fuel for 40 years, Swedish managers indicated central interim storage makes managing the spent fuel easier.

Observation: Both Sweden and Germany, although to different degrees, are shifting their programs away from reprocessing spent nuclear fuel.

Reprocessing of spent fuel from German power plants is now carried out in France and in the United Kingdom. Originally Gorleben was supposed to be the location of a reprocessing facility, but a ruling by the state of Lower Saxony in 1979 prevented this. In 1989, a proposed site for reprocessing in Bavaria (Wackersdorf) also was rejected. German policy currently provides for vitrified waste resulting from reprocessing abroad to be disposed of in German disposal sites. Although reprocessing remains a part of Germany's current waste program, recent research has emphasized direct disposal of spent fuel as an alternative to reprocessing. A pilot plant for preparing and repacking spent fuel for direct disposal is planned for construction at Gorleben.

Although the SKB in Sweden has contracted for foreign reprocessing of over 800 metric tons of spent fuel, the government has announced that no additional reprocessing contracts will be signed. The Swedes are now planning for the direct disposal of spent fuel.

Observation: Regulatory criteria used in Germany and Sweden to design and build a repository are based on radiation dose limits to individuals. By contrast, the United States is using regulatory criteria in which specific containment standards must be met.

Both the German and Swedish regulatory criteria for repository design seem less detailed. In both countries, the regulations are based on performance criteria geared toward individual radiation dose rates consistent with those proposed by the International Commission on Radiological Protection and/or International Atomic Energy Agency. New information from tests, investigations, and interactions is used by the licensing authorities to redirect the program. According to Swedish and German personnel involved in siting and building their repositories, this process provides them with the flexibility needed to develop the best possible design for a repository.

The U.S. regulatory framework is defined differently. The framework consists of system performance criteria based on a total cumulative release from the repository, rather than on individual radiation dose rates. Criteria, such as waste package lifetime and groundwater travel time, form an additional level of subsystem regulations. It appears that some subsystem criteria may not be consistent with the overall system criteria. As suggested in a September 1990 Board letter to Environmental Protection Agency (EPA) Administrator William Reilly and the Nuclear Regulatory Commission (NRC) Chairman Kenneth Carr, some of these requirements may need reexamination.

Observation: The Swedes and Germans make less of a distinction than does the United States between the applicant for a repository license and the licensing agency.

In Germany, both functions are carried out under the same government ministry, BMU. R&D are controlled by another ministry, BMFT. In Sweden, the roles of the various organizations involved in waste disposal are distinct from one another, but the relationships among the government agencies involved in disposal issues appear to be nonconfrontational. There is an emphasis among the involved organizations on working cooperatively to move the program forward.

In the United States, there is a clear distinction between the applicant for the license and the agencies involved in establishing licensing requirements. The DOE has responsibilities and authority distinct from the NRC and EPA. This arrangement may better ensure an independent review of any potential repository. Sometimes, however, this arrangement leads to adversarial relationships, thus dampening the spirit of cooperation among those involved.

Observation: In the United States, Germany, and Sweden, nontechnical issues play an important role in some waste management decisions.

Nuclear waste disposal is an issue that understandably attracts enormous public interest. Experts in both Sweden and Germany expressed the view that politics ultimately can play a decisive role. One German scientist said he thinks that political, rather than technical issues, often drive the program. For example, recent political issues (including the accident at Chernobyl) have resulted in state obstruction of all reprocessing within Germany, and since unification, Lower Saxony has stopped shaft construction at Gorleben, the possible site for a permanent repository for spent fuel.

In both Sweden and Germany, public information aspects of the high-level radioactive waste disposal programs are viewed by many as being as important as the technical aspects. Those involved underscore the need to be frank and open with the public. The importance of going to the authorities as soon as any problem develops is viewed as a basic precept in both programs. In Germany, 8,000 – 12,000 people visit Gorleben each year, and all documents are accessible to the public. In the United States, the DOE also recently began public tours to the proposed site at Yucca Mountain.

The SKB, the DOE's counterpart in Sweden, is very sensitive to public opinion and has gone to great lengths to develop and maintain a positive public image. Six to seven thousand visitors come to Forsmark each year. An information truck, sponsored by SKB, travels around the country providing the public with information about nuclear waste issues. Public confidence in Sweden in private- and public-sector capability to dispose of nuclear waste safely seems to be somewhat higher than in the United States.

Observation: Although the Swedish, German, and U.S. programs are researching the potential for high-level radioactive waste disposal in different geologic media, some topics lend themselves to further information sharing.

1. In Sweden, Germany, and the United States, technical experts are evaluating the potential for engineered barriers *in addition to* geologic barriers to safely contain the waste for thousands of years. The Swedes place much greater reliance for waste isolation on engineered barriers, specifically the waste package, than does the United States. Two methods for encapsulating fuel in a copper container are under study. According to the Swedes, a conservative estimate of the time that the high-level radioactive waste could be safely contained in either type of copper container would be 100,000 years. Their plans, however, are to design a repository system that would contain the waste for up to 1 million years. The Swedes also have designed, developed, and tested a transportation cask that can be used on ship, barge, or rail. They have five years' operational experience with this cask.

2. In Germany, the disposal plan for spent fuel currently involves studying the emplacement of 5.5-meter-long, 65-ton, triple-purpose casks in the tunnels of a repository excavated in a salt dome. The cask system, which would be used for transportation, storage, and disposal of spent fuel, includes (1) a cask for horizontal disposal in drifts and (2) a cask

for disposal in vertical boreholes. By varying the dimensions, lid designs, and internal configuration, the casks can be adapted to the requirements of different radioactive materials. The casks are being designed to remain "tight" for 500 years. Salt will presumably contain the waste beyond 500 years.

Although current DOE plans make the use of a triple-purpose, or universal, cask unlikely, information gained during container design and development in both Sweden and Germany could provide insights for U.S. technical experts.

3. Thermal loading and the potential benefits of aging waste before disposal are issues of mutual concern, especially in Sweden and the United States. The Swedes plan to place high-level waste in granite below the water table. To avoid heating the water around the high-level waste, Swedish plans call for aging the waste for at least 40 years before disposal. Extended aging of waste before emplacement is not provided for in current DOE plans. If the site at Yucca Mountain is found suitable and meets licensing requirements, plans call for emplacing high-level waste in tuff (in an unsaturated zone) at temperatures well above the boiling point of water. In the U.S. scenario, the waste would be disposed of above the water table and would raise the temperature of the rock around it.

Despite plans to place waste in an unsaturated zone, current DOE analyses of waste package materials are being performed in a saturated environment. Results of tests and analyses performed in the Swedish program could provide helpful insight into the potential effects of raised temperatures on the waste package, on the rock surrounding the waste package, on the thermal loading of a repository, and on design of a repository in a saturated zone.

4. Grouting and backfilling, to reduce secondary permeability (fracture flow), are techniques that can contribute to waste containment. As part of the International Stripa Project in Sweden, considerable study of groundwater movement in granite is underway to determine the potential transport of radionuclides. By injecting cements, silicates, clays, or other types of material into fractures near a waste package borehole, potential groundwater flow paths could be sealed or water directed away from waste packages. This technology may be of interest to the U.S. program and could be tested in various rock types.

5. Use of mechanical versus drill-and-blast tunnel-boring methods for repository construction has been an issue of concern in the U.S. program. All of the underground sites visited in Sweden were excavated by drill-and-blast techniques, a technology developed in Sweden. In discussions with several Swedish technical experts, considerable interest was expressed in the use of more innovative mechanical excavation techniques. The Swedes were knowledgeable about raise-boring technology, but appear to have very limited exposure to full-face, tunnel- and shaft-boring technology.

6. Different methods are being used in different programs to assess repository performance. The U.S. program is applying probabilistic methodology to its system safety analyses. Only a portion of the analyses of long-term repository performance conducted in Germany are probabilistic. There, geologic and geotechnical components of system safety analysis are carried out deterministically. Probabilistic methods are used primarily at the back end of the analysis. Evaluating what other countries are doing, and why and how they are doing it, could prove instructive to those doing performance assessment in the United States.

B. Conclusion

The Board's experience has shown that much can be gained by remaining apprised of technical activities underway in countries that are developing and implementing high-level waste disposal programs. In addition to maintaining contact with Swedish and German experts, the Board will make a trip to Canada this year to visit the Whiteshell Nuclear Research Establishment near Pinawa, Manitoba, where efforts are underway to investigate the potential of high-level waste disposal in granitic rock in the Canadian Shield.

Appendix A
Panel Organization

1. Panel on Structural Geology & Geoengineering

Chair:	Dr. Clarence R. Allen	Staff: Mr. R.K. McFarland
Member:	Dr. Don U. Deere	Dr. Leon Reiter
Ad Hoc:	Dr. Patrick A. Domenico	

2. Panel on Hydrogeology & Geochemistry

Co-Chair:	Dr. Patrick A. Domenico	Staff: Dr. Leon Reiter
Co-Chair:	Dr. Donald Langmuir	
Ad Hoc:	Dr. Clarence R. Allen	
Ex Officio:	Dr. Don U. Deere	

3. Panel on the Engineered Barrier System

Chair:	Dr. Ellis D. Verink	Staff: Dr. Sidney J.S. Parry
Members:	Dr. Dennis L. Price	
	Dr. Donald Langmuir	
Ex Officio:	Dr. Don U. Deere	

4. Panel on Transportation & Systems

Chair:	Dr. Dennis L. Price	Staff: Dr. Sherwood C. Chu
Members:	Dr. Melvin W. Carter	
	Dr. Ellis D. Verink	
Ex Officio:	Dr. Don U. Deere	

5. Panel on Environment & Public Health

Chair:	Dr. Melvin W. Carter	Staff: Dr. Sidney J.S. Parry
Members:	Dr. John E. Cantlon	
Ad Hoc:	Dr. D. Warner North	
Ex Officio:	Dr. Don U. Deere	

6. Panel on Risk & Performance Analysis

Chair:	Dr. D. Warner North	Staff: Dr. Leon Reiter
Ad Hoc:	Dr. John E. Cantlon	
	Dr. Patrick A. Domenico	
	Dr. Dennis L. Price	
	Dr. Ellis D. Verink	
Ex Officio:	Dr. Don U. Deere	

7. Panel on Quality Assurance

Chair:	Dr. John E. Cantlon	Staff: Dr. Sherwood C. Chu
Members:	Dr. Clarence R. Allen	
	Dr. Melvin W. Carter	
Ad Hoc:	Dr. Donald Langmuir	
Ex Officio:	Dr. Don U. Deere	

Appendix B
Meeting List for 1990–91

January 18-19, 1990

Meeting (open)
Panel on Containers & Transportation
Pleasanton, California
Topic: Briefings on the waste package environment and waste package container
Transcript available

January 18, 1990

Board Meeting (closed evening session)
Pleasanton, California
Topic: Board activities
Minutes available

January 19, 1990

Board Meeting (closed evening session)
Pleasanton, California
Topic: Board activities
Minutes available

February 1, 1990

Technical Exchange (open)
Panel on Structural Geology & Geoengineering
Denver, Colorado
Topic: DOE presentation on the exploratory shaft facilities (ESF) alternatives
Transcript not available (meeting not recorded)
Presentation briefing book available

March 2-3, 1990

Board Meeting (closed)
Tucson, Arizona
Topic: Board-related activities
Minutes available

March 19-20, 1990

Joint Meeting (open)
Panel on Risk & Performance Analysis and the Panel on Structural Geology & Geoengineering
Denver, Colorado
Topic: Repository system design requirements
Transcript available

March 20, 1990	**Ad Hoc Board Meeting (closed evening session)** *Denver, Colorado* Topic: Board activities Minutes available
March 22, 1990	**Release of First Report to the U.S. Congress and the U.S. Secretary of Energy**
April 7, 1990	**Technical Exchange (open)** **Panel on Structural Geology & Geoengineering** *Las Vegas, Nevada* Topic: Briefings by DOE on the ESF alternatives analysis study, repository configuration, and repository construction methods Transcript not available (meeting not recorded) Presentation briefing book available
April 7, 1990	**Board Meeting (closed evening session)** *Las Vegas, Nevada* Topic: Board-related activities Minutes available
April 8, 1990	**Board Meeting (closed morning session)** *Las Vegas, Nevada* Topic: Board-related activities Minutes available
April 12, 1990	**Technical Exchange (open)** **Panel on Structural Geology & Geoengineering** *Las Vegas, Nevada* Topic: DOE briefings on seismic issues at the proposed repository site Transcript not available (meeting not recorded) Presentation briefing book available
April 24-26, 1990	**Meeting (open)** **Panel on Environment & Public Health** *Las Vegas, Nevada* Topic: Presentations by the State of Nevada, the Western Shoshone National Council, and the DOE and its contractors Two-day field trip Transcript available

May 18, 1990	**Technical Exchange (open)** **Panel on Transportation & Systems with the Nuclear Regulatory Commission (NRC)** *Arlington, Virginia* Topic: NRC's role in several key issues relating to safe handling and transportation of spent nuclear fuel Transcript not available (meeting not recorded) Presentation briefing book available
May 26-June 2, 1990	**Board Trip to Sweden and the Federal Republic of Germany** Discussion of Board observations in *Third Report*
June 1990	**No meetings**
July 23, 1990	**NRC Briefing (open morning session)** *Atlanta, Georgia* Topic: NRC briefing on licensing support system (LSS) Transcript available
July 23, 1990	**Board Meeting (closed afternoon session)** *Atlanta, Georgia* Topic: Board activities Minutes available
July 24-25, 1990	**Board Meeting (closed evening sessions)** *Atlanta, Georgia* Topic: Board activities Minutes available
July 24-25, 1990	**Joint Meeting (open)** **Panel on Structural Geology & Geoengineering and the Panel on Hydrogeology & Geochemistry** *Atlanta, Georgia* Topic: ESF alternatives study and surface-based testing program Transcript available
July 26, 1990	**Board Meeting (closed)** *Atlanta, Georgia* Topic: Board activities Minutes available

August 17, 1990	**Public Hearing: Panel on Transportation & Systems** *Amargosa Valley, Nevada* Topic: Transportation and systems issues affecting the proposed repository Transcript available
August 28-29, 1990	**Meeting (open)** **Panel on the Engineered Barrier System** *Pleasanton, California* Topic: Briefings by DOE and contractors on DOE strategy for development of packaging for spent fuel and high-level waste; overview of current spent fuel studies Transcript available
September 1990	**No meetings**
October 10, 1990	**Board Meeting (open morning session)** *Arlington, Virginia* Topic: NRC/Electric Power Research Institute presentations on performance assessment Transcript available
October 10, 1990	**Board Meeting (closed afternoon session)** *Arlington, Virginia* Topic: Board activities Minutes available
October 11, 1990	**Technical Exchange (open)** **Panel on Structural Geology & Geoengineering** *Arlington, Virginia* Topic: DOE briefings on surface-based testing prioritization and Calico Hills risk/benefit analysis Transcript not available (meeting not recorded) Presentation briefing book available
October 15, 1990	**Public Hearing: Panel on Environment & Public Health** *Reno, Nevada* Topic: Environment and public health issues relating to the possibility of the development of a high-level waste repository at Yucca Mountain, Nevada Transcript available

October 16, 1990	**Meeting (open)** **Panel on the Environment & Public Health** *Reno, Nevada* Topic: Briefings by representatives from DOE, Western Shoshone National Council, State of Nevada, and the State's Nye County Office on Socioeconomic Issues Transcript available
October 22, 1990	**Meeting (open)** **Panel on Transportation & Systems** *Washington, D.C.* Topic: Transportation safeguard and operational activities Transcript available
November 1-2, 1990	**Meeting (open)** **Panel on Quality Assurance** *Arlington, Virginia* Topic: Briefings by the DOE and the NRC on quality assurance requirements and implementation process Transcript available
November 19, 1990	**Public Hearing: Panel on Transportation & Systems** *Reno, Nevada* Topic: Transportation issues concerning the development and operation of a high-level waste repository at Yucca Mountain, Nevada Transcript available
November 19-20, 1990	**Technical Exchange (open)** **Panel on Structural Geology & Geoengineering** *Denver, Colorado* Topic: DOE and contractors brief panel on interim report activities on ESF alternatives analysis study Transcript not available (meeting not recorded) Presentation briefing book available
November 28, 1990	**Release of *Second Report to the U.S. Congress and the U.S. Secretary of Energy***
December 1990	**No meetings**

January 15, 1991	**Board Meeting (closed)** *Arlington, Virginia* Topic: Board activities Minutes available
January 16, 1991	**Board Meeting (open)** *Arlington, Virginia* Topic: Briefings by environmental groups, industry groups, public policy groups, and state organizations Transcript available
January 17, 1991	**Board Meeting (open morning session)** *Arlington, Virginia* Topic: Briefings by DOE officials on the Office of Civilian Radioactive Waste Management program, systems integration, and future interactions with the Board Transcript available
January 17, 1991	**Board Meeting (closed afternoon session)** *Arlington, Virginia* Topic: Board activities Minutes available
February 1991	**No meetings**
March 1, 1991	**Meeting (open)** **Panel on Structural Geology & Geoengineering** *Tucson, Arizona* Topic: Briefings by DOE and contractors on potential and past volcanic activity within the Yucca Mountain vicinity Transcript available
March 6-7, 1991	**Joint Meeting (open)** **Panel on Structural Geology & Geoengineering and the Panel on Hydrogeology & Geochemistry** *Denver, Colorado* Topic: Briefings on site-suitability review, Calico Hills\ESF alternatives analysis study, and test prioritization Transcript available

March 14-15, 1991	**Meeting (open)** **Panel on Transportation & Systems** *Albuquerque, New Mexico* Topic: DOE and contractors' discussions on nature and scope of Waste Isolation Pilot Project transportation program Transcript available
March 26-27, 1991	**Joint Meeting (open)** **Panel on Quality Assurance and the** **Panel on Structural Geology & Geoengineering** *Dallas, Texas* Topic: Quality assurance on ESF preliminary design; follow-up on DOE quality assurance program Transcript available
April 16-17, 1991	**Board meeting on Analogues (open)** *Reno, Nevada* Topic: DOE and other presenters provide Board members with information on field studies, possible natural analogue sites, and the potential for using archaeological studies as analogues Transcript available
April 17, 1991	**Board Meeting (closed afternoon session)** *Reno, Nevada* Topic: Board activities Minutes available
April 18, 1991	**Board Meeting (closed)** *Reno, Nevada* Topic: Board activities Minutes available
May 20-21, 1991	**Meeting (open)** **Panel on Risk & Performance Analysis** *Arlington, Virginia* Topic: Performance assessment Transcript will be available

June 9-15, 1991	**Board trip to Canada**
June 25-27, 1991	**Joint Meeting (open)** **Panel on Hydrogeology & Geochemistry and the Panel on Structural Geology & Geoengineering** *Las Vegas, Nevada or Denver, Colorado* Topic: Review of proposed testing for saturated zone, unsaturated zone, rock mechanics, and geochemistry Transcript will be available
July 15-16, 1991	**Meeting (open)** **Panel on Structural Geology & Geoengineering** *Arlington, Virginia* Topic: To be determined Transcript will be available
July 16-18, 1991	**Board Meeting (open and closed sessions)** *Arlington, Virginia* Topic: To be determined Transcript will be available for open sessions Minutes will be available for closed sessions
August 12-14, 1991	**Board Trip to Waste Isolation Pilot Plant (WIPP)** *Carlsbad, New Mexico*
August 15-16, 1991	**Public Hearing: Panel on Transportation & Systems** *Denver, Colorado* Topic: Transportation issues Transcript will be available
September 4-5, 1991	**Meeting (open)** **Panel on Structural Geology & Geoengineering** *Salt Lake City, Utah* Topic: Seismic risk Transcript will be available
September 18-19, 1991	**Meeting (open)** **Panel on Structural Geology & Geoengineering** *Albuquerque, New Mexico* Topic: Borehole sealing and backfilling; ESF design review Transcript will be available

September 25-27, 1991	**Meeting (open)** **Panel on Transportation & Systems** *Arlington, Virginia* Topic: DOE update on transportation issues Transcript will be available
October 8-11, 1991	**Board Meeting (open and closed sessions)** *Las Vegas, Nevada* Topic: Thermal loading/repository design Transcript will be available for open sessions Minutes will be available for closed sessions
November 12-13, 1991	**Meeting (open)** **Panel on Structural Geology & Geoengineering** *Location to be determined* Topic: Test prioritization; site suitability (10 CFR 960); ESF design review study Transcript will be available
December 1991	**No meetings scheduled**

Appendix C
Presenters and Witnesses List

The following people made presentations to the Board or panel(s) from August 1, 1990, through January 31, 1991. This list is arranged alphabetically by organization and divided into three sections: presenters at Board meetings, witnesses at Board-sponsored public hearings, and those who submitted Statements for the Record. Citizens and independent consultants are listed at the ends of their respective sections.

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Public Hearing Witness List

The following people presented testimony at public hearings sponsored by the panels on Transportation & Systems and Environment & Public Health between August 1, 1990, and January 31, 1991. The list is arranged in alphabetical order by organization. Citizens are listed separately at the end.

Association of American Railroads
Washington, D.C.

Conan Furber
Consultant
T&S Public Hearing, November 1990

California Energy Commission
Sacramento, California
Represented by:

Lori Friel
Attorney
Western Interstate Energy Board
Denver, Colorado
T&S Public Hearing, November 1990

Daniel Nix
Co-Chair, High-Level Waste Committee
Western Interstate Energy Board
Denver, Colorado
T&S Public Hearing, November 1990

Citizen Alert
Reno, Nevada

Bob Fulkerson
Executive Director
T&S Public Hearing, November 1990

Paul Rodarte
Director, Native American Program
T&S Public Hearing, November 1990

J.R. Wilkinson
Administrative Assistant
E&PH Public Hearing, October 1990
T&S Public Hearing, November 1990

Clark County Nuclear Waste Division
Las Vegas, Nevada

Dennis Bechtel
Planning Coordinator
T&S Public Hearing, August 1990

Jerry Duke
Principal Planner
T&S Public Hearing, August 1990

Consolidated Rail Corporation
Philadelphia, Pennsylvania

Alan Fisher
Director for Operating Rules
T&S Public Hearing, August 1990

Edison Electric Institute/UWASTE Program
Washington, D.C.
Represented by:

Howard Shimon
Chairman
EEI/UWASTE Transportation Working Group
Milwaukee, Wisconsin
T&S Public Hearing, November 1990

John Vincent
Nuclear Resources Manager
GPU Nuclear
Parsippany, New Jersey
T&S Public Hearing, November 1990

Esmeralda County
Goldfield, Nevada

Brad Mettam
Project Director
T&S Public Hearing, November 1990

International Physicians for the Prevention of Nuclear War
U.S.S.R.

Zura Keshileva
Vice President
Kasakhstan, U.S.S.R.
E&PH Public Hearing, October 1990

Vladimir Popov
Secretary
Moscow, U.S.S.R.
E&PH Public Hearing, October 1990

Inyo County
Independence, California

Roger DeHart
Planning Director
T&S Public Hearing, November 1990

Charles Thistlethwaite
Associate Planner
T&S Public Hearing, November 1990

League of Women Voters of Nevada
Carson City, Nevada

Abby Johnson
Representative
T&S Public Hearing, November 1990

Nevada Nuclear Waste Study Committee
Las Vegas, Nevada

Rick Dale
Representative
T&S Public Hearing, August 1990

Ernest Travis
Representative
T&S Public Hearing, August 1990

Nevada Nuclear Waste Task Force
Las Vegas, Nevada

Judy Treichel
Executive Director
T&S Public Hearing, August 1990

Nevada State Retired Teachers Association
Carson City, Nevada

Gerard Prindiville
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E&PH Public Hearing, October 1990

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Norcross, Georgia

Ivan Stuart
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T&S Public Hearing, November 1990

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Pioche, Nevada

Geri Ann Stanton
Planning Assistant
E&PH Public Hearing, October 1990

Nuclear Waste Project Office for the State of Nevada
Carson City, Nevada

Robert Halstead
Transportation Advisor
T&S Public Hearing, August 1990

Nye County Board of Commissioners
Reno, Nevada

Stephen Bradhurst
Consultant to the Commissioners
T&S Public Hearing, August 1990

Peace Camp
Las Vegas, NV

Charles Hilfenhaus
Representative
T&S Public Hearing, August 1990

Physicians for Social Responsibility
Portland, Oregon

Dick Belsey
Member of Physicians Task Force on Nuclear Weapons & Public Health
E&PH Public Hearing, October 1990

Regional Transportation Commission of Clark County
Las Vegas, Nevada

Lee Gibson
Planning Coordinator
T&S Public Hearing, August 1990

Sierra Club
Reno, Nevada

Marjorie Sills
Representative
E&PH Public Hearing, October 1990

State Senator
Fallon, Nevada

The Honorable Virgil Getto
T&S Public Hearing, August 1990

Western Shoshone National Council
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William Rosse, Sr.
Chair, Environmental Protection Commission
E&PH Public Hearing, October 1990
T&S Public Hearing, November 1990

Citizens:

Ken Garey
Amargosa Valley, Nevada
T&S Public Hearing, August 1990

Mike Gilgan
Amargosa Valley, Nevada
T&S Public Hearing, August 1990

Bill Greis
Las Vegas, Nevada
T&S Public Hearing, August 1990

Charles Holtz
Amargosa Valley, Nevada
T&S Public Hearing, August 1990

Doris Jackson
Amargosa Valley, Nevada
T&S Public Hearing, August 1990

Thomas Tabacco
Carson City, Nevada
T&S Public Hearing, November 1990

Bill Tobin
Reno, Nevada
E&PH Public Hearing, October 1990

Shane Tureson
Reno, Nevada
E&PH Public Hearing, October 1990

Frederick George Wilson
Sparks, Nevada
E&PH Public Hearing, October 1990

Statements for the Record

The following individuals submitted statements to the Board for the record.

Board of County Commissioners, Lincoln County
Pioche, Nevada

Edward Wright
Vice-Chairman

U.S. Department of Energy
Yucca Mountain Project Office
Las Vegas, Nevada

Carl Gertz
Project Manager

Western Shoshone Elders Council
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Alyce Williams
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Citizens / Consultants:

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Cynthia Mitchell
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Harold Rogers
Citizen
Carson City, Nevada

Richard Schimdt
Citizen
Reno, Nevada

Appendix D
The German and Swedish Nuclear Waste Disposal Programs — Background

Overview of Sweden's Nuclear Waste Program

Background

According to recently published reports, 45 to 50 percent of Sweden's electricity currently is produced by nuclear reactors located at four sites: four reactors at Ringhals, which is on the west coast; two reactors at Barsebäck, which is on the southwest coast near Denmark; and three reactors at Oskarshamn and Forsmark, both of which are located on the east coast of Sweden. Sweden's first reactor was commissioned in 1972, and its two newest reactors were commissioned in 1985. According to a publication of the Swedish Nuclear Fuel and Waste Management Company (SKB)—the company responsible for managing the Swedish nuclear waste disposal program—Sweden is totally dependent on "imports of uranium and certain services within the nuclear fuel cycle."*

Despite its reliance on nuclear power, a public referendum in 1980 led to a parliamentary decision that by 2010 all nuclear power plants in Sweden would cease operation and be decommissioned. If this decision remains in effect, Swedish utilities can fairly accurately project the amounts of low-, intermediate-, and high-level waste that will need disposing of in the coming years (7,800 metric tons of spent fuel; 230,000 cubic meters of low- and intermediate-level waste; 110,000 cubic meters of decommissioning waste).**

There is some, but not a great, effort to date to reconcile the large energy shortage that will occur if the parliamentary decision goes into effect. During the Board's visit to Sweden, Dr. Bjurström, president of the SKB, stated that even with the moratorium, energy use will increase 2 percent annually. He said the country is searching for an energy policy that will satisfy all political parties; natural gas supplies from Denmark, Norway, and the Soviet Union are under consideration. Other professionals indicated that potential global greenhouse effects of fossil fuel combustion may influence Sweden's eventual energy strategy.

SKB's philosophy, however, is that regardless of the future of nuclear power, there still will be nuclear waste to dispose of. One participant suggested that the referendum to phase out nuclear power may in

* Dr. Sten Bjurström, President, SKB. Introductory Statement to the NWTRB in "SKB- Swedish Nuclear Fuel and Waste Management Company-Activities." May 27, 1990.

** Sweden and Germany use a system to classify nuclear waste that is slightly different from that used in the United States. *Spent fuel* is nuclear fuel that has been irradiated to the extent of its useful life. *High-level* waste is the waste stream resulting from the first cycle of fuel reprocessing. It contains long-lived radionuclides found in spent fuel and requires both heavy shielding and cooling to be handled safely. *Intermediate-level* describes waste with significant beta/gamma activity but generally low alpha activity. It requires some radiation shielding, but no cooling. *Low-level* waste contains negligible amounts of long-lived radionuclides and can be handled without shielding. *Decommissioning* waste consists of parts of the nuclear reactor activated and/or contaminated during operation of the reactor. In Sweden, decommissioning waste is classified as low- and intermediate-level waste. See the Glossary for U.S. definitions of spent fuel, high-level waste, low-level waste,and transuranic waste.

fact help focus public attention on the need to solve the nuclear waste problem. There is already a consensus in the country to handle its own waste problems and not export them to other countries.

Organizational Structure

Swedish law has determined that responsibility for the safe management and final disposal of the radioactive waste produced by nuclear power plants in Sweden belongs to the nuclear power utilities. SKB, which was created in 1972 and is jointly owned by four utilities, is the company responsible for all handling, transportation, storage, and permanent disposal of spent nuclear fuel and radioactive waste from nuclear power plants. The company also is responsible for the planning and construction of all facilities and pertinent research and development work.

A number of government agencies review and assess the activities of the SKB. They include (1) the National Board for Spent Nuclear Fuel (SKN), (2) the Swedish Nuclear Power Inspectorate (SKI), and (3) the National Institute of Radiation Protection (SSI). SKN, a small governmental agency of 10 people reporting to the Ministry of Environment, is the central authority responsible for evaluating and supervising the nuclear industry's research and development program on the management and disposal of spent nuclear fuel and the safe decommissioning and dismantling of nuclear plants.

SKN administers the Swedish system for financing nuclear waste management. The projected costs of all waste handling, storage, and disposal facilities in Sweden is approximately $8 billion. This total includes the costs of Forsmark and CLAB, the interim storage facility, and the projected cost of decommissioning and dismantling all nuclear power plants and other facilities.

SKI and SSI are larger agencies with regulatory powers to supervise the safety and radiation protection aspects of nuclear power. These agencies are responsible for studying and appraising the nuclear safety and radiation protection of proposed facilities and processes. SKI employs approximately 90 people and operates on an annual budget of $17 million. SSI employs approximately 130 people and operates on an annual budget of approximately $10 million.

The SKB System

SKB has developed a waste management system for the collection, transport, storage, and disposal of spent fuel and radioactive waste that consists of a ship built specifically to transport nuclear waste, and facilities at Forsmark (the Swedish Final Repository for low- and intermediate-level radioactive waste) and at Simpevarp (Central Storage Facility for Spent Nuclear Fuel - CLAB). CLAB, located adjacent to the Oskarshamn Power Station on the east coast south of Stockholm, is an interim storage facility for spent nuclear fuel. CLAB will be able to accommodate fuel into the late 1990s.

Although some reprocessing has been contracted for by SKB, no additional reprocessing is planned.* The decision not to reprocess resulted partly from economic concerns and partly from concerns about nuclear proliferation. Current policy and practice are to store spent fuel at the reactors for one year, then transfer it to CLAB, where it will age for approximately 40 years prior to final disposal.

SKB recently announced plans to begin characterizing three Swedish sites for a permanent high-level waste repository (SFL). The sites will be named in 1992. Site-characterization activities should start in 1993. Detailed investigation of two sites will begin in 1996. After the government decides on a suitable site (about 2006), SKB will build a permanent repository for high-level waste. Construction is planned to begin by 2010.

* Reprocessing is the recovery of fissile material from irradiated nuclear fuel by chemical separation from fission products and other radionuclides.

Transportation

Since all Swedish nuclear power plants are located along the coast, low-, intermediate-, and high-level waste is transported by ship. The *M/S Sigyn* is a combined roll-on, roll-off and lift-on, lift-off vessel. Machinery, electrical system, and so on, have been designed for high reliability, and the cargo hold is surrounded by a double hull and a double bottom, to ensure high floatability and to contain and protect the cargo in the event of collision or grounding. The ship measures 90 x 18 meters with a draft of 4 meters; payload maximum capacity is 1,400 metric tons. After the ship puts into a harbor, terminal transport vehicles convey the transport casks from the ship's hold to the various facilities and vice versa.

The transport cask, designated the TN17-Mark 2, is 6.15 meters long and 1.95 meters in diameter. It is fabricated from forged steel with a stainless steel coating. The cask can carry 17 boiling water reactor assemblies (3.0 MTU) or 7 pressurized water reactor assemblies (3.1 MTU) and has a gross weight of 80 metric tons. The cask is equipped with cooling fins to limit the fuel assembly temperature to no more than 450°C. The cask was designed to withstand a free fall from a height of 9 meters, a fire for 30 minutes at 860°C, and an external pressure equivalent to a water depth of 4,000 meters. Since 1985, 1,200 metric tons of spent fuel have been transported to CLAB without incident.

Waste transportation is planned in close cooperation with the nuclear power plants. Lead time for scheduling a shipment is about one year. A description file is prepared for each category of waste to be deposited in the Swedish Final Repository (SFR). The file contains information on content, manufacturing process, and requirements made on each package in connection with transport and disposal. Data on content and radiation level are collected and stored in a computerized waste register at the nuclear power plant and in the SFR. The data are used to plan the emplacement of different packages in the SFR. When the waste arrives at the SFR, personnel know exactly where each package is to be placed.

SFR Forsmark Nuclear Power Station

The Forsmark Station, the final repository for low- and intermediate-level waste, is located on the east coast of central Sweden, north of Stockholm. The SFR site is near the power plant at a depth of about 50 meters below the Baltic seabed outside the harbor. The sea depth over the site is approximately 5 meters. The waste is stored in various chambers built at the SFR into a large rock cavern.

Transports to and among the different parts of the underground repository take place using special diesel-powered, rubber-tired waste transport vehicles via a two-lane tunnel system. Two parallel, kilometer-long access tunnels connect the SFR with the surface. The operating tunnel is the larger of the two access tunnels and is used during the deposition phase for all waste transports.

Intermediate-level waste from the operation of Swedish nuclear power plants, as well as similar radioactive waste from industrial and medical sources and from the research plant at Studsvik, is disposed of in the SFR. Total capacity of the SFR is about 90,000 cubic meters. Neither spent nuclear fuel nor other high-level waste will be disposed of in the SFR. The SFR will remain operative until the nuclear power plants have been decommissioned (2010) and dismantled (about 2025).

Four storage chambers were built at the SFR based on the variety of waste to be stored there and the type of packaging to be used. The chambers are 160 meters long but vary in width, height, and interior design.

- Two rock chambers accommodate intermediate-level waste in concrete tanks.
- One rock chamber accommodates intermediate-level waste in concrete molds, metal drums, etc.
- A silo holds intermediate-level waste in concrete molds, metal drums, etc.

The silo, which receives the waste containing the most radioactivity, has been equipped with special engineered barriers against the future escape of radioactive materials. The vault has a diameter of 30 meters and a height of 70 meters. (The silo within it is 50 x 26 meters.) A barrier of bentonite clay fills the space between the slipform-cast silo and the vault containing it. The inside of the silo is divided into square vertical pits, measuring 2.5 meters per side. After a layer of waste packages has been emplaced, it is grouted with concrete. All handling in and around the silo takes place in radiation-shielded areas using automatic or remote-controlled equipment, commandeered from a control center.

Materials buried in the rock vaults are surrounded by a series of barriers. The outermost barrier is the rock mass that hosts the SFR. When the SFR is filled, it will be sealed, or backfilled, and the tunnels will be blocked with concrete. After sealing, the drainage pumps will cease, and the repository will gradually fill with water. The barriers are intended to prevent, or retard, the transport of radioactive materials with the groundwater.

CLAB — Interim Storage for Spent Nuclear Fuel

The Central Storage Facility for Spent Nuclear Fuel (CLAB) is a wet-pool interim storage facility designed to hold spent fuel from all Swedish nuclear power plants from the time it leaves the cooling pools at the nuclear power plants until removal for final disposal (30-40 years). At the time CLAB was designed (1976), the technology of storing waste in dry casks was in its infancy and not expected to be licensable. Consequently, dry-cask storage was not considered seriously.

When spent fuel is discharged from the reactor, it is stored on-site for approximately one year in a spent fuel pool. It then is shipped to CLAB. Although shipping cask capacities could be increased by leaving the spent fuel at the reactors for a longer period of time, this is not done because of limited lifting capabilities at the reactors. Some pools have higher density racks, but newer reactors are not so equipped because of the existence of CLAB.

The storage building is in a rock cavern, the roof of which is located about 25 meters below ground level. All handling and storage of the fuel takes place underwater in four storage pools and one small central pool. Transportation down to the storage area takes place in a water-filled container that runs in its own elevator shaft. Each pool holds 3,000 cubic meters of water and 750 metric tons of spent fuel in storage canisters.

According to the president of SKB, Dr. Sten Bjurström, CLAB will not become the permanent repository.

SFL — Swedish Final Repository for High-Level Waste

Since 1977, SKB has undertaken a number of site investigations to determine the geologic conditions prevailing at potential final disposal sites. Specifically, SKB is examining the properties of the bedrock, the pattern of fracture zones, and the physical and chemical conditions of the groundwater. The investigations are performed in and adjacent to rock formations that are thought large enough to host all the spent fuel (7,500 metric tons) that will be generated by the year 2010. Demographics, transport conditions, and economics also are being considered. A large number of sites (14) were investigated from 1977 to 1985.

SKB has developed a number of repository concepts. The concept that has been most thoroughly studied is referred to as KBS-3, which is similar in some ways to the repository concept being proposed in the United States for Yucca Mountain. Other concepts examined by SKB include very deep boreholes, very long inclined or horizontal undersea boreholes, as well as other innovative underground designs.

The KBS-3 concept consists of an array of parallel tunnels excavated at a depth of approximately 500 meters, at a selected site in Swedish Precambrian bedrock, which is more than 600 million years old and underlies a good part of the Scandinavian peninsula. According to current plans, the parallel tunnels would be 3.3 x 4.5 meters. They would be located 25 meters apart. Along the floor of the tunnels, vertical holes would be excavated, 1.5 meters in diameter, 7.5 meters deep, at intervals of 6 meters. Waste canisters would be placed in these holes, and the holes and tunnels then backfilled with compacted bentonite clay.

Although the spent fuel is to be aged for at least 40 years prior to emplacement in the repository, residual heat still will be generated by the waste. To restrict the maximum geologic temperature to no greater than 80°C, a typical waste canister would be loaded with approximately 1.4 metric tons of spent fuel and would have a thermal output of approximately 800 watts when placed in the repository. The local area power density for this configuration would be approximately 22 kilowatts per acre. If an optional, two-level repository is adopted, and the two levels are separated by 100 meters, the 80°C-maximum temperature constraint would be met by increasing the tunnel spacing to 33 meters, center-to-center. Such a configuration would have a local areal power density of 33 kilowatts per acre. (The proposed Yucca Mountain configuration has an equivalent loading of 57 kilowatts, or 57,000 watts, per acre.)

The proposed SKB waste package would consist of a copper canister, 0.8 meters in diameter and 4.5 meters long. Two alternative methods are being studied for fuel encapsulation. In one method, the spent fuel assemblies are placed in a fabricated copper canister; the cavity is filled with molten lead, and a lid is then welded to the canister.

In the second method, the cavity would be filled with copper powder and a lid placed on the canister. The canister would then be heated in a furnace to 500°C, placed in a pressure cell, and subjected to an isostatic pressure of 150 MPa,* thereby transforming the copper powder to solid copper, and joining the lid tightly to the canister. The completed canisters would weigh between 18.6 and 22 metric tons, depending on the encapsulation method used. The resulting canisters are expected to contain the radionuclides for at least 100,000 years.

SKB has developed a plan for siting and developing its proposed geologic repository. In summary, the plan entails the following steps:

1992-94 Identification and preliminary investigations of three candidate sites.

1994-96 Approval of two sites for detailed site investigation.

1996 Selection of shaft location at each site.

1996-2002 Shaft sinking and detailed site characterization.

2003-06 Final selection and licensing of site.

2010 Start of construction.

2020 Start of waste emplacement.

2020-50 Expansion of repository and successive selection of emplacement positions.

Stripa Mine Research Project

The Stripa mine has been used by SKB as a site for research on techniques for long-term storage of radioactive waste in granite. The mine is located in an old mining district, a three-hour drive west of Stockholm. The Stripa mine, which was mined out in early 1977, is considered a "very dry mine." The total length of the drifts is approximately 25 kilometers, and the deepest mining level is 430 meters. The mined-out ore consisted of a quartz-banded hematite and occurred in a leptite formation. Adjacent to the leptite is a large body of grey-to-light-red, medium-grained granite. The age of the granite has been determined to be Precambrian. All experiments are carried out in this formation.

Work began at Stripa in late 1976. The Stripa Project (1977-1980) was a Swedish-American cooperative project with three parts.

- Heater experiments
- Assessment of fracture hydrology
- Geophysical measurements

* MPa (megapascal) is a measure of pressure. 1MPa = 145.04 pounds per square inch.

As a result of experiments, extensive information was obtained on the mechanical response of the rock to heat load and on the groundwater flow in the rock.

This initial research led in 1980 to the International Stripa Project, which involves investigation of groundwater-rock/engineered barrier interactions. Development of methods and techniques for such studies and the verification of previously obtained laboratory results are the general objectives of the project. There are several fracture systems, but the majority of the fractures are sealed mainly with chlorite, occasionally with calcite. About 500 meters of new drifts have been excavated into the granite formation from the existing drifts at the 360-meter level in the mine. Smooth-wall blasting techniques were used when the new drifts were excavated to minimize fracturing of the walls of the tunnel.

The project is carried out autonomously under the sponsorship of the Organization for Economic Cooperation and Development's Nuclear Energy Agency and is managed by the SKB. Over the course of the project, participating countries have included Canada, Finland, France, Japan, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Sweden contributes $8 million; the United States contributes $4 million; the other countries each contribute $2 million. Total contributions amount to more than $25 million. Research is divided into the following areas.

Detection and mapping of fracture zones

This involves developing geophysical and hydraulic methods and instruments to detect and map fracture zones. Electromagnetic, radar, seismic, and hydraulic techniques also are being evaluated. Holes have been drilled in the rock, and special tools built that employ inflatable "packers" to seal off given sections of the hole while pressure and flow-rate tests are conducted.

Groundwater characteristics and nuclide migration

Water sampling in boreholes down to a maximum depth of 1,230 meters is undertaken to determine the chemical properties and history of the groundwater. This includes sampling and analysis of water in crystalline rock to increase knowledge about the extent to which leaking radioactive material may be transported by groundwater. Investigations also involve developing methods to determine the hydraulic conductivity of the rock in both vertical and horizontal boreholes. Migration tests were performed using sorbing and nonsorbing tracers. In one drift, hundreds of square-meters of rock face were "wallpapered" with plastic sheeting in 2-square-meter sections to catch the water as it migrated out of the higher rock. Nonradioactive tracers were injected into the water above the drift, and the arrival at this catch system was carefully recorded.

Bentonite clay for backfilling and sealing

Activities involve testing the integrated behavior of heat-producing waste canisters, bentonite materials, rock, and groundwater in the Precambrian granite. In one test, large heaters were inserted into caverns to simulate canisters of nuclear waste. The caverns were sealed with bentonite, a clay that is a known barrier against moisture and heat. Bentonite clay also is being investigated as a potential sealing material for boreholes, shafts, and tunnels.

Researchers are presently in Phase III of the project, which is directed toward the investigation of groundwater flow, as well as fracture sealing, and the redirection of flow from the waste. Phase III began in 1986 and will be completed in 1991.

Overview of Germany's Nuclear Waste Program

Background

By the end of 1989, 21 nuclear power plants were operational in the western half of Germany. They provided approximately 40 percent of the electrical power produced in the West (population about 60 million). The installations used approximately 400 metric tons of spent nuclear fuel annually.

No further construction of nuclear power plants is anticipated for the foreseeable future, in part because of the negative public attitudes toward nuclear power since the Chernobyl accident. Changes brought about through the unification of the two Germanys in October 1990 may result in a reevaluation of Germany's energy policy. Since unification, five nuclear power plants in what used to be East Germany have been deemed unsafe and were to be shut down by January 1, 1991. Such decisions may affect current nuclear waste disposal plans.

During its trip to the Federal Republic of Germany (Germany), the Board visited two sites: Gorleben and Asse. The Gorleben interim storage facility is located approximately 180 miles southeast of Hamburg on the Elbe River. The Asse II Salt Mine is located just southeast of Braunschweig and is the site for current research and development into direct disposal of spent nuclear fuel.

German Waste Management Strategy as of Spring / Summer 1990

The German spent nuclear fuel and high-level waste management concept stems from provisions in federal law enacted since 1979 and involves five major elements. They are (1) interim storage of spent fuel at nuclear power plants and in off-site interim storage facilities, (2) reprocessing of spent fuel and reuse of the nuclear material recovered in nuclear power plants, (3) development of direct disposal for spent fuel for which reprocessing is not technically feasible nor economically viable, (4) conditioning and intermediate storage of high-level waste in interim storage facilities, and (5) disposal of spent fuel and high-level waste in a deep geologic repository. Permanent disposal means the waste cannot and will not be retrieved.

Until recently, German policy and funding had focused on developing domestic reprocessing capacity, relying on France and Great Britain for reprocessing services in the interim. Under the German Atomic Energy Act, Germany must reprocess its spent nuclear fuel unless it is economically or technically infeasible. The Karlsruhe experimental reprocessing plant (WAK) had been in operation since 1987 at the nuclear research center in Karlsruhe. The WA-350 commercial reprocessing plant at Wackersdorf, Bavaria, was designed and completed. Also, plans were initiated to develop a reprocessing plant at Gorleben. In mid-1989, however, domestic reprocessing was totally abandoned for political and economic reasons. The political climate against nuclear power has become even stronger since Chernobyl. Also, one of the utilities, VEBA, entered into a cost-effective agreement with France for a joint reprocessing venture. Germany also is negotiating for reprocessing services with British Nuclear Fuels, despite mounting pressure in Great Britain against reprocessing foreign spent nuclear fuel. For now, Germany has abandoned all efforts at domestic reprocessing and intends to rely on France and Great Britain for reprocessing services in the future. Waste resulting from reprocessing will be shipped back to Germany, where the heat-generating waste will be disposed of in a repository located in a salt dome (possibly Gorleben).

The current focus in Germany is on the development of a program for direct disposal of spent fuel. A "Research and Development Program on Direct Disposal" has been launched, covering the time period 1986-1994. This program consists of building a pilot-scale conditioning and encapsulation plant at

Gorleben, where demonstration tests are being performed on a 1:1 scale*. Cask development and transport studies and drift and borehole emplacement studies, including thermal simulation studies are being conducted as part of this project. A number of tests are being conducted at the Asse II Mine Research Site. The second part of the project consists of examining several different repository designs and configurations in an effort to determine a system for permanently disposing of both waste resulting from reprocessing and spent nuclear fuel in a common repository.

All findings from the aforementioned and other studies will be available before the licensing procedure for Germany's first heat-generating waste repository begins. Many of the tests and studies have been conducted or are in the latter stages at this time. German plans provide for a permanent repository, possibly at Gorleben, licensed and built by the year 2008**. Approximately $300 million has been budgeted to develop the capability to dispose of the spent fuel and high-level waste.

Organizational Structure

The responsibilities for spent fuel management and waste disposal are divided among the federal government, the states, and the utilities. The federal government is to coordinate the German nuclear program, sponsor R&D, build and operate radioactive waste disposal facilities, and set licensing rules. Waste management activities are federally licensed, but state governments actually issue the licenses, acting in the name of the federal government. The utilities transport and perform conditioning and disposal of the spent nuclear fuel and reactor waste.

While the utilities remain legally responsible for waste disposal, the current Federal Environment Minister has imposed a plan for reorganizing the industrial sector's participation in waste management activities. Specifically, competition for waste management services has been eliminated. A new subsidiary of the federal railway, Nuclear Cargo and Service (NCS), is now a monopoly transporter of spent fuel and radioactive wastes in Germany. The firm GNS, Company for Nuclear Service, owned by the nuclear utilities (80%) and STEAG Kernenergie GmbH (20%), now holds a monopoly on waste treatment and will take over operations at the Gorleben and Ahaus facilities.

There are several key organizations in Germany for managing radioactive wastes working under the Federal Ministry for Research and Technology (BMFT) and the Federal Ministry for Environmental Protection and Reactor Safety (BMU). The Board met with personnel from some of these organizations (shown in boldface below) during its trip to the Gorleben site and the Asse research mine.

The BMFT is the federal ministry with research and development authority on radioactive waste management. Under its auspices are:

- GSF/IFT (Company for Radiation and Environmental Research/Institute for Underground Storage under the BMFT) manages the waste disposal R&D program and operates the Asse mine facility. GSF has made the Asse mine available for a number of the tests that are part of the R&D program on direct disposal and is participating in these tests. This organization, under the direction of Prof. Dr.-Ing. Klaus Kühn, organized and coordinated the Board's FRG trip.

- **BGR (Federal Institute for Geosciences and Natural Resources)** has been involved with geologic surveys and with salt dome repository R&D and is assisting in research projects underway at Asse.

- **KfK (Karlsruhe Nuclear Research Center)** is a research organization (somewhat similar to a U.S. national laboratory) that has been involved with R&D of spent fuel management including reprocessing, waste treatment, and vitrification.

* Conditioning is the process of disassembling and cutting spent fuel elements to ready them for encapsulation. Encapsulation is packaging the spent fuel for permanent storage.

** The current Social Democratic government of Lower Saxony has stalled the excavation work on a second exploratory shaft in the Gorleben salt dome. PNL/IPSO *Highlights Report*, December 1990.

- The Alternative Spent Fuel Management Technologies Project Group (PAE) at Karlruhe is coordinating the R&D Program on Direct Disposal.

The BMU is responsible for storage, transportation, and disposal of radioactive wastes. Unlike the U.S. program, where construction/operation and licensing responsibilities are divided between the Department of Energy and Nuclear Regulatory Commission, respectively, the BMU also is responsible for nuclear safety and radiation protection and for supervision of state licensing activities. Under its auspices are:

- BFS (Office for Radiation Protection), established in 1989 under the BMU, is responsible for licensing transport and storage of waste, for constructing and operating waste repositories, and for conducting nationwide radiological monitoring. It will act as future owner of the permanent repository on behalf of the federal government. (BFS assumed the duties of the former PTB.)

- **DWK (German Fuel Reprocessing Company)**, established and funded by the nuclear power utilities, was previously responsible for spent fuel management including reprocessing and for radioactive waste storage and treatment. Due to the recent change in reprocessing policy in the FRG, DWK's responsibilities have changed to developing cask and spent fuel conditioning technologies.

- **GNS, Company for Nuclear Service** owned by the Nuclear Utilities (80%) and STEAG (20%), is responsible for the pilot-conditioning facility (PKA) at Gorleben. The PKA will be a facility for the development and demonstration of conditioning processes for spent fuel prior to direct disposal.

- **DBE (Company for Construction and Operation of Waste Disposal Facilities)**, a consortium of mining companies reporting to the BFS, is responsible for the construction and operation of Gorleben. DBE has been commissioned to carry out the demonstration projects under the direct disposal R&D program and to plan the permanent repository.

- **RSK (Federal Reactor Safety Commission) and the SSK (Radiation Protection Commission)** issue licensing requirements on behalf of the BMU.

Interim Storage Before and After Reprocessing

Wet storage of spent fuel is provided at most reactors for three to ten years, but some reactors with less capacity use dry storage in dual-purpose nodular cast iron casks, similar to those used at the Virginia Electric Power Company's Surry reactor. Interim away-from-reactor storage at Gorleben and/or Ahaus also is planned. Ahaus GmbH., a daughter company of DWK and STEAG Kernenergie GmbH., Essen, managed construction of the facility at Ahaus, located on the western border between Germany and the Netherlands. Each facility's capacity is approximately 420 canisters or a maximum of 1,500 metric tons of uranium. Interim storage at both facilities has not been implemented to date.

If spent fuel is reprocessed, it will be transferred to foreign reprocessing facilities within about one to five years from the time it is discharged from the reactor. Interim storage of acidic high-level liquid waste (to be vitrified) is carried out in metal tanks. Dry storage of vitrified high-level waste in metal casks at away-from-reactor facilities is planned but has not yet been implemented.

A number of reasons were suggested by DWK personnel for selecting dry-cask technology over wet-pool storage for interim storage.

1. It is cheaper.

2. It is passive.

3. It can be designed for no releases.

4. There is no technical limit on its lifetime.

5. It is easy to decommission.

6. It is more politically acceptable because it appears less permanent.

7. There are advantages to using the casks for both transportation and storage.

8. It is flexible in that additional storage capacity can be added easily.

Transportation

Almost all transportation of nuclear waste in Germany is by rail except for the fuel undergoing reprocessing in the United Kingdom, which has to be loaded on ships to cross the English Channel. Some waste is transported by truck, but dedicated trains are not used because of local opposition from environmental groups. During transportation, police are present but no satellite tracking takes place. Until recently, private industry was responsible for all transportation of the waste.

Now, the Nuclear Cargo Service (NCS), a subsidiary of the federal railway, has assumed that responsibility. It is not clear, however, what the impact of this change will be. It seems likely industry will continue to transport the waste, only now it will be under the auspices of the NCS.

Permanent Disposal

A maximum of 333,000 cubic meters of spent nuclear fuel and high-level waste is anticipated by the year 2000. Solidified high-level waste is destined for deep geologic disposal, but efforts are also underway to examine the potential for permanently disposing of reconditioned waste and spent fuel at the same site. The Gorleben salt dome is under investigation as a candidate site for a permanent repository for all categories of waste and spent nuclear fuel. The Konrad mine, planned for full operation in the early 1990s, would be the final disposal site for approximately 200,000 cubic meters of low- and intermediate-level waste (up to the year 2000). Spent fuel—which cannot be stored at Konrad—would have to be placed in interim dry storage until Gorleben is operational. Other low-level waste could continue to be stored in conventional facilities, such as state-operated storage sites, at reactors, and at the interim fuel rod storage facility at Gorleben, until final storage at Konrad or Gorleben is available.

Currently, Gorleben has the capacity to store 1,500 metric tons of spent fuel or high-level waste in dry storage for up to 40 years. Its storage capacity for low-level waste is approximately 40,000 drums, containing 200 liters each. The facility employs a staff of approximately 60 people.

Studies are underway at the Asse II Research Mine and elsewhere to determine the potential for disposing of the waste at Gorleben. The current plan is to emplace the waste at a depth of about 800 meters. Above-ground exploration has been carried out, and below-ground exploration was started in 1986 with the sinking of shaft No. 1. If the Gorleben site is ruled acceptable for a repository, the facility is expected to be operational in about 2008.

Both Gorleben and Asse are associated with salt domes; large (14 and 8 kilometers, respectively) dome- or mushroom-shaped salt formations, which extend to within 250 meters of the ground surface and whose source is the 2,000-meter deep Permian (240-million-year-old) Zechstein salt formation. The advantages of using a salt dome as a repository are (1) the absence of water over many millions of years, otherwise the salt would have dissolved; (2) high plasticity leading to self-sealing of fissures and drillholes and, in the long term, of the mined cavities containing the waste; (3) high-heat conductivity of the salt; and (4) good performance of the salt during mining operations. The salt's impermeability may be compromised by the presence of "impurities" such as anhydrite, the pores of which can contain water, and which can form seams that could act as preferential pathways for water. Another potential problem could be the presence of polyhalite, a mineral that contains structural water. The salt in Asse contains only about 0.04 percent water. The movement of salt to fill in the mined cavities approaches several centimeters per year at some locations. It was observed that crushed salt is being used to backfill drums of low-level waste, and that the less dense crushed salt surrounding the drums is being compressed by the inward flow of surrounding salt bedrock. The salt eventually seals the drums off so completely that their emplacement is invisible to the naked eye except for a fine fracture in the salt.

The Konrad iron ore mine is located in the Salzgitter area, about 35 miles southeast of Hannover. From 1976 until 1982, the Company for Radiation and Environmental Research investigated the mine's features for its suitability as a possible repository. Upon successful completion of the tests, an application was submitted, initiating licensing procedures. Since waste with a negligible thermal output is to be disposed of at Konrad mine, and because extensive reprocessing is expected to take place, the bulk of the material generated in western Germany is planned for storage at Konrad. (With reprocessing, more than 95% of the total volume would be suitable for the mine.) The facilities will be able to handle 20,000 cubic meters with initial peaks of up to 40,000 cubic meters, while employing approximately 250 people.

Engineered Barriers

There are two types of casks being considered primarily for transportation and interim storage.* One system consists of casks, made of nodular cast iron. Although approved for use in dry storage in the United States, they have not been approved for use in transportation because the Nuclear Regulatory Commission considers cast iron to be too brittle. The casks range in size from 2 to 15 metric tons. These casks have been subjected to extensive safety tests over a period of several years. The second system consists of casks made of forged steel. Some versions have been approved for use in the United States.

The permanent disposal plan for spent fuel currently involves the emplacement of 5.5-meter-long, 65-ton, triple-purpose casks in drifts of a repository mine in a salt dome. This cask system, which would be used for transportation, storage, and disposal of spent fuel, comprises (1) cask for horizontal disposal in drifts and (2) canister for disposal in vertical boreholes. By varying the dimensions, lid systems, and internal configuration, the canister can be adapted to the requirements of different radioactive materials. The canister is designed for final disposal of spent fuel rods. Transport and interim storage of wastes in canisters, however, can be done only in shielded containers.

Present plans call for the casks to be manufactured of a manganese-nickel steel alloy. Coating techniques that prevent corrosion also are being investigated. The casks will have two lids; the inner one will be screwed on and the outer one will be welded to the container. The design criteria are based on "tightness" lasting 500 years.

Research Projects

The Asse II salt mine was purchased by the Federal Ministry of Research and Technology in 1965. The mine is being used to investigate the potential suitability of the Gorleben site to be a permanent repository and to develop methods for the disposal of low- and intermediate-level waste. Asse currently holds 124,500 drums of low-level waste and 1,300 drums of intermediate-level waste. Although more than adequate space and technical capacity exist here to dispose of other low- and intermediate-level waste, disposal was stopped for political reasons.

The research and development program at the mine is conducted under the auspices of GSF. The objectives of the program are as follows.

1. Investigate rates and amounts of water and gas release resulting from production of heat and gamma radiation by nuclear material and the resulting increased pressure inside sealed disposal boreholes.

2. Develop and test transportation and handling systems for canisters of high-level radioactive waste.

* The terms cask, container, and canister refer to slightly different entities, depending on a particular country's definition. For purposes of this report, the European definitions are used. Cask means a massive container used to transport and/or store irradiated nuclear fuel. It provides physical and radiological protection and dissipates heat from the fuel. Canister refers to a receptacle designed to hold spent fuel or radioactive material to facilitate movement and storage. (Note that the term canister is used in Sweden and Germany in those instances where the term container would be used in the United States.)

3. Investigate thermally induced stresses and resulting pressure loads to the waste canisters, the deformation and closure of rooms, galleries, and pillars above the disposal boreholes.

4. Develop and test suitable methods and techniques to obtain data on safety during construction and operation of a repository.

Many experiments are being conducted to determine the thermal and mechanical properties of salt, the effect of gamma radiation (which appears to be very limited), and the rates and distances at which different brines migrate. All in all, a wide range of experiments are being conducted that should provide the knowledge needed to successfully characterize the salt and to safely dispose of the waste.

In the Asse mine, two parallel drifts have been excavated, each of which is to accommodate three dummy containers equipped with electric heaters and backfilled with crushed salt. Measuring instruments evaluate the thermal and mechanical behavior of the formation and backfilling material.

Two strategies for final disposal are being pursued. In one, full-scale mockups of self-shielded, 65-ton Pollux casks are placed in a tunnel and backfilled with salt. In the other, full-scale mockups of smaller Pollux canisters are lowered into vertical boreholes about 15 meters deep (versus actual depth of 300 meters in the repository). The purpose of the tests is to determine the suitability of these methods for disposing of spent fuel and vitrified* high-level waste from reprocessing. The maximum temperature permissible in the salt as a result of waste emplacement is 200°C. A shaft transport system also is being tested. The system must have a load capacity of 800 kilonewtons (180,000 pounds force). Machines capable of approximately 650 kilonewtons are to be developed, constructed, and tested for use in emplacing the waste.

* Vitrified high-level waste is one form of reprocessed waste. It is the conversion of high-level waste materials into a glassy or noncrystalline solid for disposal. Under the German program, waste reprocessed in France may, in part, return to Germany in vitrified form.

Appendix E
Department of Energy Response to the Recommendations made in the Board's *Second Report* (November 1990)

As part of its effort to keep the Nuclear Waste Technical Review Board informed of its progress, the Department of Energy submitted to the Board on March 29, 1991, a summary of initial responses to recommendations the Board made in its *Second Report*. The Board has included those responses along with the transmittal letter in this report. Inclusion of these responses does not necessarily imply Board concurrence.

Department of Energy
Washington, DC 20585

March 28, 1991

RECEIVED
MAR 29 1991

Dr. Don U. Deere
Chairman, Nuclear Waste Technical
Review Board
1100 Wilson Boulevard
Arlington, Virginia 22209

Dear ~~Dr. Deere~~ Don:

On behalf of the Department of Energy (DOE) and the Office of Civilian Radioactive Waste Management (OCRWM), I would like to thank the Nuclear Waste Technical Review Board (NWTRB) for its thoughtful and effective review of our site evaluation, waste packaging, environment, and transportation activities.

Enclosed are DOE's responses to the Board's recommendations in its Second Report to the U.S. Congress and the U.S. Secretary of Energy. The responses address the seven broad areas of the Board's recommendations. You will note that a number of the responses refer to past DOE/NWTRB technical interactions and ongoing evaluations that will provide a basis for significant program decisions. We will keep the Board informed of progress in these evaluations.

I would like to take this opportunity to call to the Board's attention the relationship between technical issues addressed by the Board and our strategic planning for the program. As you know, we have been conducting a series of predecisional workshops with representatives of interested and affected parties, in order to obtain their input to strategic principles and plans for the programs. These workshops are proving to be highly valuable in helping us select, focus, and prioritize the strategic issues and decisions we must address. The results of these workshops will be reflected in our Mission Plan Amendment to be issued later this year.

Among other contributions, the Strategic Principles workshops are demonstrating how technical issues, such as those addressed by the Board, are embedded in program strategy and in timing and sequencing of technical activities. It is evident that our ability and need to interact with the Board on technical issues will be strongly driven by program evolution, and we will keep the Board advised of our priorities and needs in order to aid the Board's planning for use of its resources.

Another factor which will affect the priorities and content of our interaction with the Board is our progress and plans for characterization of the Yucca Mountain site. As you know, we are currently trying to resolve the impasse with the State of Nevada which is preventing us from expanding our site evaluation activities. When new surface-based and underground evaluation activities do get started, they will be highly focused on determining if the Yucca Mountain site, and the geologic setting it provides, is a suitable location for a high-level waste repository.

With this strategic focus for Yucca Mountain activities, we expect emphasis on acquisition of site data and its use in evaluating site suitability. Acquisition and use of data for repository and engineered barrier system design will have a secondary priority, since effort on repository features will depend first on whether or not the site is suitable, and second on what the site properties that affect the engineered systems are.

I would, therefore, like to suggest that the agenda for the interactions between the Board and OCRWM be selected, to the extent practicable, to reflect the focus on issues of current strategic importance within each technical sector, as indicated above. I will direct our staff to work closely with the Board to achieve this objective.

I greatly appreciate the many contributions the Board has already made toward helping assure quality and effectiveness in the OCRWM program, and I look forward to a continuing productive relationship.

Sincerely,

John W. Bartlett

John W. Bartlett, Director
Office of Civilian Radioactive
Waste Management

Enclosure

DEPARTMENT OF ENERGY RESPONSES TO RECOMMENDATIONS IN THE NUCLEAR WASTE TECHNICAL REVIEW BOARD'S *SECOND REPORT* (November 1990)

INTRODUCTION

The Nuclear Waste Policy Amendments Act of 1987 established the Nuclear Waste Technical Review Board to evaluate the technical and scientific validity of activities undertaken by the Department of Energy (DOE) in the Civilian Radioactive Waste Management Program.

The Board is required to report, not less than two times per year, to the Congress and the Secretary of Energy its findings, conclusions, and recommendations. The Board has issued two reports to date. The first report was released in March 1990. The second report was issued on November 27, 1990. The second report contains 20 recommendations in 7 broad areas: (1) effects of seismicity and faulting on facility design and site suitability; (2) testing for site suitability; (3) performance assessment; (4) long-lived waste packages; (5) waste container materials, configurations, and disposal environments; (6) coordination and integration of environmental studies; and (7) human factors and system safety in transportation and handling of spent fuel.

These recommendations and DOE's responses are presented in this report. Each recommendation is quoted verbatim from the Board's report of November 27, 1990, and is followed by the response.

EFFECTS OF SEISMICITY AND FAULTING ON FACILITY DESIGN AND SITE SUITABILITY

In these recommendations to DOE, the Board addresses how potential seismic and faulting risks should be considered in determining site suitability and developing criteria for facility design.

Recommendation 1

Increased emphasis should be placed on understanding the engineering, public safety, and environmental consequences of seismic events at Yucca Mountain, including earthquakes of magnitudes larger than those that are likely to occur during the lifetime of the facility.

Response

DOE will include engineering, public safety, and environmental consequences of seismic events and other natural hazards in the basis for determining the suitability of a site or a design. Earthquakes are potential events in the region during a repository's operational and postclosure periods; however, it is their potential consequences to workers and public health and safety that are of primary concern, not their potential for occurrence. The evaluation of these consequences should be based on the analysis of a range of potential seismic events; including those high-magnitude events that have a relatively low probability of occurring during the lifetime of the facility. DOE has completed a preliminary evaluation of this type, and the results are described in a report by Subramanian et al., (1989).

As discussed with the Board's Structural Geology and Geoengineering Panel during the April 12, 1990, meeting on seismic hazards, it is the current DOE policy that the seismic design basis for the repository facilities is to be an earthquake large enough to have a very low probability of occurring during the lifetime of the facility. Once a design basis is selected, further design analyses will be carried out to evaluate the consequences of hypothetical events that are both larger and smaller than the design basis. DOE is concerned with this approach in that the hypothetical very-low-probability, high-magnitude events that are used in conducting such evaluations may be taken to be the "expected" by the public and regulatory agencies. This may lead to pressure to adopt increasingly more conservative designs that may be unwarranted when the probability of the event and its potential consequences are considered. DOE believes that analyses are important in evaluating the response of repository facilities to events that exceed facility design bases and for evaluating the potential health and safety consequences of any failures that may result from a seismic event or other natural hazard.

Reference

C. V. Subramanian, N. Abrahamson, A. H. Hadjian, L. J. Jardine, J. B. Kemp, O. K. Kiciman, C. W. Ma, J. King, W. Andrews, and R. P. Kennedy, *Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities*, SAND88-1600, Sandia National Laboratories, Albuquerque, New Mexico, 1989.

Recommendation 2

Discussions of site suitability should be based on the likelihood of adverse consequences and not on the occurrence of earthquake ground motion or fault displacement alone.

Response

DOE concurs that the ultimate determination of site suitability should be based on the potential consequences of seismic events or other hazards, in conjunction with their potential for occurrence. DOE is currently developing a methodology for an early determination of site suitability and will continue analyses of this type as additional information on natural hazards becomes available. In addition, the Test Prioritization Task will focus on identifying the parameters and activities needed to increase confidence in the assessments of site performance. This information will be used in developing the site-suitability methodology.

In licensing the repository, emphasis should be placed on evaluating the health and safety consequences of a wide range of potential events (e.g., the potential for releases of radionuclides to the accessible environment) rather than placing regulatory emphasis on the potential occurrence of a specific design event or natural phenomena related to a particular hazard. The evaluation of health and safety consequences should include the consideration of high-probability events that are equal to or smaller than a nominal design-basis event and very-low-probability events that may exceed a given design basis. The implementation of such an approach does not necessarily mean that additional information on the nature of potential natural hazards is not required.

Considerable additional information will be required to adequately define the range of potential events and the probability of occurrence of specific events within that range and to increase confidence that the results provide the appropriate degree of "reasonable assurance."

Recommendation 3

Formulation of a specific tectonic model, acceptable with a high degree of confidence, should not be viewed as a prerequisite to site suitability or to ensuring public safety and environmental protection.

Response

DOE shares the Board's view that the formulation of a specific tectonic model, acceptable with a high degree of confidence, is not necessary for assessing site suitability. As explained in the Site Characterization Plan (SCP), section 8.3.1.17.4.12, and as discussed with the Board's Structural Geology and Geoengineering Panel on April 12, 1990, DOE is committed to the formulation and evaluation of tectonic models that include the range of credible descriptions of the candidate site. Since these alternative conceptual models are expected to differ significantly in their prediction of the potential effects of tectonics on waste isolation (e.g., through prediction of differing effects over time of crustal strain, faulting, and volcanism on gas and fluid travel paths and travel time or on water-table elevation), their use will assist DOE to assess the range of uncertainty in estimates of repository performance.

If performance estimates based on data-constrained models and subsequent numerical models vary widely with a resulting high degree of uncertainty regarding total-system radionuclide releases, DOE will seek to reduce uncertainty by designing tests, collecting additional data, and performing analyses to identify the more plausible alternative models.

The explicit formulation and evaluation of a full range of credible tectonic models will help increase public confidence that all plausible and significant tectonic events and scenarios that could occur during the preclosure and the postclosure periods have been considered.

Recommendation 4

Geologic licensing criteria and standards for the repository and its surface facilities should reflect the nature and relative vulnerability of the repository complex and the problems it poses. The criteria and standards should ensure public safety and environmental protection in light of current scientific knowledge and engineering practice, including the feasible mitigation of adverse consequences.

Response

DOE concurs that licensing criteria and standards should reflect the nature and relative vulnerability of a repository complex as discussed in the Board's recommendation. As discussed with the Board's Structural Geology and Geoengineering Panel on April 12, 1990, DOE's comments on the NRC draft technical position "Methods of Evaluating the Seismic Hazard at a Geologic Repository" (June 1989) are consistent with the Board's position that suitability should be judged on the basis of the potential risk, and not just on the potential occurrence of a natural phenomena, such as earthquake ground motion or fault displacement, independent of consequences to health and safety. DOE has taken the position that Appendix A to 10 CFR Part 100 should not be used in siting and licensing a repository and its surface facilities because of the marked differences between the hazards posed by a nuclear reactor and the hazards posed by a geologic repository, and because Appendix A relies on outdated risk-assessment techniques. (See also the response to Recommendation 2.)

TESTING FOR SITE SUITABILITY

The following Board recommendations on proposed geologic tests are made so that site suitability can be evaluated by DOE as early as possible.

Recommendation 5

Planned scientific testing of the Yucca Mountain geologic block should be re-evaluated to give highest priority to those tests and studies that provide the data essential to assess the suitability of the site. Each proposed study should be evaluated in terms of procedures, technologies, test locations, and appropriateness in meeting stated objectives.

Response

DOE is addressing the Board's recommendation that the highest priorities be given to tests and studies that will provide the data essential for assessing the suitability of the candidate site. As noted by the Board, DOE has initiated a management and technical analysis, known as the Test Prioritization Task (TPT), to identify and prioritize site-characterization tests that could influence early decisions about the suitability of the candidate site. Preliminary results were discussed at the October 11, 1990, meeting with the Board. The phase 1 report of the TPT was completed on March 1, 1991 (DOE, 1991a) and results were discussed at the Structural Geology & Geoengineering and Hydrogeology & Geochemistry joint panel meeting held on March 6, 1991.

TPT activities are now included as part of the Early Site Suitability Evaluation (ESSE) and will make use of the integrated results obtained from the Calico Hills Risk/Benefit Analysis (DOE, 1991b) and the Exploratory Shaft Facility Alternatives Study (Stevens and Costin, 1991) as part of this effort. If new concerns are identified by the ESSE, they will be factored into the test prioritization efforts.

Study Plans have been or are being developed for the tests identified in the Site Characterization Plan and considered as part of the TPT. These Study Plans describe the procedures, test locations, and the appropriateness of these tests for meeting their stated objectives, which will be evaluated as part of the Study Plan formal review process. Further management or technical review of individual studies or activities may be necessary to implement the approved recommendations of the site suitability task dependent upon the issue under consideration. (See also the response to Recommendation 2).

References

U.S. Department of Energy, *Testing Priorities at Yucca Mountain: Recommended Early Tests To Detect Potentially Unsuitable Conditions for a Nuclear Waste Repository*, YMP, Las Vegas, Nevada, 1991.

U.S. Department of Energy, *Risk/Benefit Analysis of Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain*, YMP-91-6, Las Vegas, Nevada, 1991.

Stevens, A.L. and L.S. Costin, *Findings of the ESF Alternatives Study, An Executive Report*, SAND90-3232, Albuquerque, New Mexico, 1991.

Recommendation 6

The DOE should consider expanding its development program for dry-drilling equipment to include the capability to drill inclined holes.

Response

DOE recognizes the potential benefits of inclined boreholes to maximize investigative capabilities relative to near-vertical joint and fault systems. As the Board has noted, DOE has developed new technology to recover core from vertical boreholes at depths of several thousand feet without introducing any fluids, as discussed at the October 11, 1990, meeting with the Board. Specifications for the dry-coring system include a borehole size of approximately 12-14 inches to allow for instrument installation and long-term monitoring. As a result of the required specification, the present system consists of a heavy dual-wall pipe with an open-center rotary type reaming bit which allows core recovery ahead of the reaming bit. However, because of the design of the present system (particularly because of estimated induced sideloads on the drill bit) inclined deep dry drilling and dry coring are not feasible with the present system.

DOE's current plans are to evaluate the need for additional data on near-vertical structures and will compare the costs and the benefits of drilling inclined boreholes with other means of obtaining similar information, such as in-situ testing along exploratory drifts in the Topopah Springs or the Calico Hills unit from the underground test facility. If a need is demonstrated, then DOE will evaluate options. Such an analysis would evaluate the need for dry drilling in boreholes and could also consider a broad range of possibilities within the existing drilling technology, including air-drilled inclined boreholes without core recovery and "wet-drilled" (including air foam) inclined boreholes with core recovery.

PERFORMANCE ASSESSMENT

In these recommendations to DOE, the Board addresses methodologies and alternative approaches that can be used for assessing repository performance.

Recommendation 7

The DOE should continue using decision-aiding methodology to provide more explicit and formal means for relating program decisions to risk and performance issues. Such methods should be used in an iterative and ongoing fashion to explain the reasoning behind major programmatic decisions before these decisions are committed. The four existing DOE task force studies applying these methods should be closely coordinated.

Response

DOE will continue using decision-aiding methodology when appropriate for relating program decisions to risk and performance issues. In the past, DOE has used decision-aiding methodology for a comparative analysis of five potential repository sites (DOE, 1986). Two other studies that have used decision-aiding methodologies and have been closely coordinated are the Calico Hills Risk/Benefit Analysis (DOE, 1991) and the Exploratory Shaft Facility Alternatives Study (Stevens and Costin, 1991).

DOE will employ decision-aiding methodologies in an iterative manner to evaluate major programmatic decisions centered around test prioritization, design issues, and performance issues as appropriate. DOE will maintain a high degree of coordination between various groups applying decision-aiding methodologies (e.g., the Test Prioritization Task now included in the Early Site Suitability Evaluation).

References

DOE (U.S. Department of Energy), 1986, *A Multiattribute Utility Analysis of Sites Nominated for Characterization for the First Radioactive Waste Repository - A Decision-Aiding Methodology*, Office of Civilian Radioactive Waste Management, RW-0074, Washington, D.C.

DOE (U.S. Department of Energy), *Risk/Benefit Analysis of Alternative Strategies for Characterizing the Calico Hills Unit at Yucca Mountain*, YMP-91-6, Las Vegas, Nevada, 1991.

Stevens, A.L. and L.S. Costin, *Findings of the ESF Alternatives Study, An Executive Report*, SAND90-3232, Albuquerque, New Mexico, 1991.

Recommendation 8

The DOE should continue to develop methods for assessing expert judgment in areas of significant uncertainty. Furthermore, the DOE should incorporate into the current task force studies the views of technical experts <u>*outside*</u> *the DOE and its contractors. The basis for each expert judgment needs to be carefully documented.*

Response

DOE will continue to use expert judgment effectively in making decisions that require its use. Emphasis is being placed on documenting the decision process, including the basis for the expert judgment used in the process. Other issues DOE is addressing include the question of bias and coordinating multiple expert-judgment panels so that they complement each other.

Efforts in the past where significant outside expertise has been used as part of, or in review of, programmatic initiatives include: 1) establishing the basis for the tectonics evaluation in the Environmental Assessment (DOE, 1986); 2) the cost/benefit analysis of seismic design for waste handling facilities; 3) the peer review to evaluate planned studies with respect to calcite-silica deposits; 4) the evaluation of the Szymanski hypothesis; 5) a peer review of the unsaturated zone hydrology program; and 6) a peer review for geophysical methods for site characterization.

In the past year DOE has employed several outside experts in decision analysis in the course of ongoing studies, to obtain the views of DOE and DOE contractor personnel who are considered to be experts in areas with high uncertainty. In the future, DOE will continue to seek opportunities to use a diverse group of experts and, where appropriate, increase the use of different outside experts on major issues where peer reviews are warranted.

Reference

DOE (U.S. Department of Energy), 1986, *Final Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada*, DOE/RW-0073, Washington, D.C.

Recommendation 9

The DOE should consider investigating more extensively the use of the natural analogues to support performance assessment for a potential repository at the Yucca Mountain Site.

Response

DOE continues to be interested in using data from analogue studies to support performance assessment. Several activities focused on analogue studies are underway or are being planned. For example, DOE recently completed field work on a multinational natural-analogue study in Brazil. Data from this study will be used as a test case in the next phase of the INTRAVAL project, an international effort focused on the techniques and limitations of validating performance-assessment models. The conclusions and consensus that develop from the INTRAVAL project on validation techniques and limitations may have a bearing on similar efforts in the OCRWM program.

DOE also monitors natural-analogue work in other countries and participates in the Natural Analogue Working Group under the Council of European Communities. (The objective of the Working Group is to promote understanding and consensus on the use of analogue studies in geologic disposal programs.) In addition, DOE is considering participation in a number of new international cooperative analogue studies.

In its plans for the characterization and performance assessment of the Yucca Mountain candidate site, DOE is considering the use of natural-analogue studies, including analogues for hydrothermal systems and other natural systems, as well as analogues for engineered systems and human activities. The needs of performance assessment will play a significant role in developing criteria for selecting new analogue studies and the technical review and evaluation involved in planning and managing the studies. As part of this effort, DOE is developing guidance for the selection of analogues and the conduct of studies. DOE also will consider the applicability of data associated with weapons testing at the Nevada Test Site, with the intent to cooperate with ongoing and contemplated analogue studies. In addition, data from natural-analogue studies may provide methods for the validation of models used in performance assessment. Close coordination between DOE's work on natural analogues and performance-assessment activities was established during planning for fiscal year 1991, and it will continue during the planning of future activities.

LONG-LIVED WASTE PACKAGES

These Board recommendations stress the importance of using long-lived waste packages as a means of ensuring repository performance.

Recommendation 10

At a future meeting, the DOE should respond to the Engineered Barrier System (EBS) Panel's four questions of January 6, 1990, relating to EBS performance. It should be emphasized that the Board's interest in a robust, extended-life EBS does not imply a diminished interest in the geologic barriers' contribution to overall repository performance; rather, the Board is suggesting engineered barriers may reduce the adverse consequences associated with difficult-to-predict geologic or climatological events occur.

Response

DOE is continuing to consider the implications of the questions raised in January 1990 by the Board's Engineered Barrier Systems Panel on the performance of the engineered-barrier system (EBS). To address these questions, we are using a structured systems-engineering approach, as reflected, for example, in the development of the Waste Package Plan (YMP/90-62).

A key consideration in responding to questions about the feasibility of developing waste packages designed for very long performance is a clear understanding of the challenges of demonstrating performance with reasonable assurance. Such a demonstration must address complex interactions among the components of the waste package and the repository environment, and it must rely on predictions that cannot be validated over long times.

As detailed in the Waste Package Plan, the first steps in systematically developing and evaluating waste-package concepts include determining requirements and defining the characteristics of the waste form and the near-field environment. Reports addressing these factors are being developed. These reports, together with the planned EBS workshop (discussed in the response to Recommendation 11), represent the initial steps in responding to this recommendation.

Reference

U.S. Department of Energy, *Yucca Mountain Project Waste Package Plan*, YMP/90-62, Las Vegas, Nevada, 1990.

Recommendation 11

A workshop should be held to investigate the practicality, advantages, and disadvantages of developing a robust, extended-life EBS that would contribute to containment for periods of time well beyond 1,000 years. The Board would be pleased to assist in developing an agenda for such a workshop.

Response

DOE has initiated planning for a workshop with the objective of investigating the practicality of developing concepts for a robust, extended-life EBS, as recommended by the Board. This workshop is tentatively scheduled for June 1991. The format of the workshop will permit the structured presentation of a number of alternative EBS concepts by DOE and other interested parties. Such a workshop would involve convening qualified individuals in the appropriate disciplines to discuss the practicality, advantages, and disadvantages of pursuing the development of such concepts. Preliminary planning for this workshop has been informally discussed with the Board's staff, and DOE will continue to keep the Board apprised of the workshop plans as they are developed.

WASTE CONTAINER MATERIALS, CONFIGURATIONS, AND DISPOSAL ENVIRONMENTS

These Board recommendations to DOE pertain to evaluating further a number of options on waste package design.

Recommendation 12

Studies of alternative materials should be restarted. These studies should include evaluation of container materials and designs, emplacement designs, and container configurations, including both internal adsorbing materials and external backfill materials.

Response

Since the release of the Board's second report, DOE has completed and issued the Waste Package Plan. This plan, which has been provided to the Board, describes a comprehensive process for developing alternative design concepts for the waste packages and other components of the engineered-barrier system, including the identification and evaluation of alternative materials, as recommended by the Board. In the meeting with the Board's Engineered Barrier System Panel on August 28-29, 1990, DOE described the approach and plans for implementing this process. The pace of implementation for this plan will be dictated by the priority assigned to development of the engineered systems and the availability of resources.

As stated in the Secretary's Report to the Congress in November 1989, major activities related to the design of a repository and the waste package are being deferred, pending availability of more information concerning the suitability of the candidate site. DOE does, however, intend to proceed with limited implementation of the plan, as resources permit.

References

U.S. Department of Energy, *Yucca Mountain Project Waste Package Plan,* YMP/90-62, Las Vegas, Nevada, 1990.

U.S. Department of Energy, *Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program,* DOE/RW-0247, Washington, D.C., 1989.

Recommendation 13

Heater tests should be re-initiated. These tests should examine the effects of alternative emplacement orientations and three-dimensional and multiple heat sources for a range of thermal loads.

Response

OCRWM does not currently have access to a suitable facility for performing in situ field tests in an unsaturated welded volcanic tuff. Therefore, it will not be possible to conduct field tests using electrically-heated simulators of waste packages prior to the development of the ESF.

Recommendation 14

The EBS development and testing program should be coordinated and funded at a level sufficient to produce a statistical basis for assessing its contribution to long-term predictions of repository behavior. Tests should be long-term preferably exceeding five years and include both laboratory and field testing.

Response

DOE will coordinate and fund long-term laboratory and field testing to provide a sound basis for predicting the contribution of the EBS components to the performance of the repository system. Limited laboratory tests, primarily involving the degradation of container materials and mechanisms for the release of radionuclides from spent fuel and vitrified high-level waste, have been underway for several years. These tests have focused on the identification and quantification of the phenomena that affect waste-package performance as opposed to statistically testing all of the EBS configurations that have been considered.

Long-term laboratory testing, especially when it involves tests of radioactive materials or tests in ionizing-radiation environments, are inherently costly in test facility preparation and operation. Therefore, DOE has been conservative in committing resources to these tests until the EBS concept development has advanced to a level of maturity where materials have been selected and the test environment parameters have been established. The process for establishing these selections and parameters is discussed in the responses to Recommendations 10 and 12.

In regard to producing a statistical basis, DOE believes that the Board's recommendation may not be practical, because of the diversity of characteristics, particularly for the waste forms, and the multiple interactions between materials that are possible. The intent of the testing strategy is to address characteristic diversity by carefully selecting representative materials for testing and to identify the most significant degradation modes and interactions to establish the long-term test matrix.

It is DOE's strategy to initiate field tests when the exploratory shaft facility becomes available and, assuming that the candidate site is determined to be suitable, to continue them, as appropriate, as an integral part of a performance confirmation program as required under Subpart F of 10 CFR Part 60. This approach would allow the tests to continue during the licensing and repository construction period.

COORDINATION AND INTEGRATION OF ENVIRONMENTAL STUDIES

These Board recommendations pertain to the need for the environmental study program at Yucca Mountain to be coordinated with respect to the various stakeholders involved and integrated with respect to the different subject areas of investigation.

Recommendation 15

The DOE should continue to include in its study plans the interests and concerns of Native Americans, the States of California and Nevada, the National Park Service, the Soil Conservation Service, and the Fish and Wildlife Service.

Response

DOE will continue to work with these parties and devote considerable effort to satisfy their concerns and interests. The following information summarizes the actions taken by DOE.

Sixteen Official Tribal Representatives (OTRs) from the various bands and Tribes in the area have been interacting with DOE on a regular basis regarding programmatic activities and events. These OTRs have been interacting with DOE for almost 2 years, and DOE intends to continue these interactions. Currently, DOE is discussing and developing methods whereby Native American concerns can be addressed in the course of Yucca Mountain Project environmental activities. Additional discussions with the OTRs are expected to be scheduled in the spring of 1991.

DOE has developed an environmental field program that it believes is technically appropriate to the site characterization phase. This program consists of ongoing monitoring programs in the areas of air quality, meteorology, terrestrial ecosystems, archaeology, reclamation, and background radiation. Water-resource monitoring and regional soil surveys will begin later this spring. All DOE management plans describing these field monitoring programs were shared with the State of Nevada.

DOE has not finalized environmental study programs in the State of California. DOE is conducting passive ongoing monitoring activities in California. In the near term, the DOE may need to commence water-sampling studies and other ecological surveys in and around the Ash Meadows area. These studies will be planned in consultation with the U.S. Fish and Wildlife Service

(USFWS) and the National Park Service (NPS), both of whom have an interest in the area. When activities are near commencement in the State of California, DOE plans to contact appropriate State agencies to ensure regulatory compliance and to keep the State of California apprised.

DOE has held several meetings with NPS regarding water monitoring. NPS had filed a protest to DOE's application, submitted to the State of Nevada, for water usage during site characterization. The effect of potential drawdowns are the primary issues of concern to NPS. As a result of several discussions, DOE accelerated the preparation of a monitoring plan specific to the concerns of NPS. This monitoring plan addresses the measurement of water levels in a monitoring network located south from Yucca Mountain to the Ash Meadows area. The plan was finalized and submitted to the NPS on March 12, 1991 (DOE, 1991). In the transmittal, Yucca Mountain Project requested that NPS lift their protests to the water appropriation permit application and let the State know that they are lifting their protests. NPS has indicated that it will lift its protest.

Both the "Environmental Field Activity Plan for Soils" and the "Reclamation Implementation Plan" were sent to the Soil Conservation Service (SCS) for review and comment, and the agency's comments were incorporated into the final documents. A regional soil survey is expected to commence in April 1991 and will be conducted in accordance with SCS guidelines.

DOE worked closely with USFWS to develop a desert tortoise research and protection program even before the designation of the desert tortoise as an endangered species. After the designation, DOE prepared a biological assessment that formalized this program. It was accepted with minor changes by USFWS, and which issued a "No Jeopardy Biological Opinion" in February 1990. Since then, DOE has kept USFWS apprised of site investigations, and such interactions are expected to continue. DOE also sent its "Yucca Mountain Site Characterization Project Environmental Training Program" to USFWS for review and comment, and this document was subsequently amended in response to their comments.

Consultation with the Bureau of Land Management (BLM) concerning compliance with applicable parts of the Federal Land Policy and Management Act has resulted in the issuance of two right-of-way reservations one for access to approximately 52,000 acres of BLM-administered land and one for access to 19,000 acres of the Nellis Air Force Range. In addition, a 12 year land withdrawal from mining and mineral leasing laws for 4,255.5 acres of BLM land immediately over the proposed repository block was granted to maintain the physical integrity of the subsurface environment. In achieving these milestones, several environmental issues were addressed that resulted in stipulations designed to protect the environment.

Finally, DOE plans to continue discussions with all of the above mentioned agencies to the maximum extent practicable. DOE will continue to keep the Board informed of how the interests and concerns of these parties are included in the study plans.

References

U.S. Department of Energy, *Biological Assessment of the Effects of Site Characterization Activities on the Endangered Desert Tortoise*, Yucca Mountain Project Office, Las Vegas, Nevada, 1989.

U.S. Department of Energy, *Draft Reclamation Implementation Plan for the Yucca Mountain Project*, Yucca Mountain Project Office, Las Vegas, Nevada, 1990.

U.S. Department of Energy, *Draft Environmental Field Activity Plan for Soils,* Yucca Mountain Project Office, Las Vegas, Nevada, 1990.

U.S. Department of Energy, *Monitoring Program for Groundwater Levels and Springflows in the Yucca Mountain Region of Southern Nevada and California,* Yucca Mountain Project Office, Las Vegas, Nevada, 1991.

Recommendation 16

The DOE and the State of Nevada should explore the possibility of initiating a cooperative program to develop baseline environmental information.

Response

DOE has, in the past, extended several offers to the State to participate in DOE programs, but these offers have not been pursued by the State. DOE has also transmitted several requests to the State and its contractors to coordinate their environmental field activities with those of DOE in order to adequately protect the limited faunal populations at the site. This coordination is desirable to prevent oversampling of populations stressed by drought conditions, and to protect the desert tortoise, a species designated as threatened by the Federal Government. The State has not responded as of this date.

During the site characterization phase, DOE's objectives in the environmental arena are threefold: (1) to monitor the effects of site characterization activities and to develop and implement mitigation strategies as appropriate; (2) to collect monitoring data as part of an overall field program that may be used to fulfill potential permitting requirements; and (3) to conduct environmental activities to fulfill prerequisites established by DOE management for the initiation of site characterization activities. The environmental data gathered by these activities do not cover all the topics generally considered part of an "environmental baseline." However, all data gathered may be considered as "background" information to be used as corroborative data in support of the future baseline.

DOE believes that establishing an environmental baseline is an activity associated with the environmental impact statement (EIS) and will be initiated after the EIS scoping hearings and completion of the EIS Implementation Plan. The NWPA required that an environmental assessment (EA) be prepared on the basis of available data and that it provide an assessment of potential significant adverse environmental impacts due to site characterization activities. These analyses, as documented in the EA, determined that no significant adverse impacts were expected to result from site characterization. However, DOE has developed and implemented an extensive monitoring program in air quality, meteorology, background radiation, ecosystems, archaeology, and water resources to gather background data during site characterization so as to monitor site characterization activities. Establishing an environmental baseline prior to the conduct of the EIS scoping hearings may be interpreted as prejudging the results of the scoping process.

Reference

U.S. Department of Energy, *Final Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada,* DOE/RW-0073, Washington, D.C., 1986.

Recommendation 17

All environmental programs at the Yucca Mountain Site funded by the Nuclear Waste Fund should be developed and conducted in a manner that the data obtained are appropriate to and can be used during licensing.

Response

DOE will ensure that all environmental data needed for licensing will be developed such that it is usable for that purpose.

Recommendation 18

An integrated environmental program that takes cognizance of ecosystem processes should be developed for the Yucca Mountain Site. The results of this program should permit assessment of the effects of site characterization and repository construction and operation on the local ecosystem. The program also should provide a basis for understanding ecologic pathways for any radioactive materials that might escape containment during repository construction, operation, and decommissioning.

Response

DOE has developed an integrated environmental program that focuses on the needs of the different project phases.

DOE believes that its program will identify ecosystem processes at Yucca Mountain and will evaluate the effects of repository development (including site characterization), construction, and operation on the local ecosystem. Since the program is currently in the site characterization phase, the environmental program is directed at addressing ecological concerns associated with site characterization. The potential effects of repository construction, operation, closure, and decommissioning will be addressed when the process of developing the EIS is begun with the publication of a notice of intent and EIS scoping hearings.

The current DOE ecosystem program addresses five areas: (1) site characterization effects; (2) desert tortoise research and mitigation activities; (3) reclamation feasibility studies and reclamation actions as necessary; (4) support to the radiation-monitoring program in small-mammal sampling; and (5) preactivity surveys, required as prerequisites to the management approval of site-characterization activities.

HUMAN FACTORS AND SYSTEM SAFETY IN TRANSPORTATION AND HANDLING OF SPENT FUEL

These Board recommendations pertain to enhancing the safety of spent fuel transportation when the scale of future transport activities becomes significantly large.

Recommendation 19

The NRC should develop policy statements, program guidelines, and, if feasible, criteria documents in human factors and system safety engineering that will help ensure that DOE's and utilities' system acquisition programs address future accident potentials. The goal should be for the system acquisition programs to be complete in all the technologies that can contribute to operations safety and efficiency, including emergency and mitigation planning.

Response

The Nuclear Regulatory Commission is the appropriate organization to respond to this recommendation. However, these activities are being addressed in the development of the OCRWM programmatic and physical system requirements documents.

Recommendation 20

Priority should be placed on developing a high-level waste management system that minimizes the handling of spent fuel.

Response

DOE recognizes that increased handling of spent fuel could lead to additional operational exposures and potential for mishandling incidents. DOE will limit the handling of spent fuel in the Federal waste-management system to the extent practicable and consistent with system operational requirements. DOE is also working with representatives of the utility industry to ensure compatibility between the Federal system and the spent-fuel storage options being pursued at the utility sites.

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Standards and Regulations

10 CFR 60 (Code of Federal Regulations). 1990. Title 10, *Energy,* Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories." Washington, D.C.

40 CFR 30 (Code of Federal Regulations). 1990. Title 40, Part 30, "General Regulation for Assistance Programs for Other than State and Local Governments." Washington, D.C.

40 CFR 31 (Code of Federal Regulations). 1990. Title 40, Part 31, "Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments." Washington, D.C.

40 CFR 191 (Code of Federal Regulations). 1984. Title 40, *Protection of the Environment,* Part 191, "Environment Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. " Washington, D.C.

48 CFR 15 (Code of Federal Regulations). 1990. Title 48, Part 15, "Containing and Codification of Documents of General Applicability and Future Effect." Washington, D.C.

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Glossary

Because this report will be of interest to technical and nontechnical readers, a glossary of scientific and technical terms has been compiled to aid readers in understanding such terms used in the report. It is not meant to be a formal glossary, nor to have the completeness of a dictionary, but rather, it is intended to help the reader understand in a general sense technical terms used regularly by the Board.

Accessible environment: The atmosphere, land surface, surface water, oceans, and portions of the earth's crust that are outside of the controlled area (the area that will be marked by suitable monuments extending no more than 5 kilometers in all directions from the repository boundary).

Alluvium: A surface or near-surface deposit of unconsolidated or poorly consolidated gravel, sand, silt, or clays deposited by a stream or other body of running water

Analogue: A thing or part that is analogous. As used in this report, a given natural setting or anything impacted by, or resulting from, human activity that can provide information on aspects of repository performance. Analogues generally are broken into two categories: natural and anthropological. Natural analogues occur through natural phenomena. Anthropological analogues result from human activity. "Archaeological analogue" generally is used to refer to an analogue resulting from the activities of ancient cultures.

Backfilling: The placement of materials, originally removed or new, into the excavated areas of a mine, including waste-emplacement holes, drifts, accessways, and shafts

Baseline: Defined and controlled element (e.g., configuration, schedule, data, values, criteria, or budget) against which changes are measured and compared

Block: An undeformed mountain-sized section of rock that may be bounded by large faults and/or large-scale topographic features (e.g., river valleys)

Biosphere: The zone of planet earth, where life naturally occurs, extending from the deep crust to the lower atmosphere. Earth's living organisms.

Borehole: An excavation, formed by drilling or digging, that is essentially cylindrical and is used for exploratory purposes

Borings: Holes drilled into the earth, usually vertically from the surface, but may be inclined

Caisson: As used in the DOE programs, a caisson is a cylindrically shaped pipe, set vertically and with its open end upwards, packed with solid materials such as crushed tuff, and used to study the transport and sorption of dissolved species under saturated or unsaturated flow conditions. Caissons are often several feet in diameter.

Canister: The structure surrounding a waste form (e.g., spent fuel rods) that facilitates handling for storage, transportation, and/or disposal

Cask: A massive container used to transport and/or store irradiated nuclear fuel or high-level nuclear waste. It provides physical and radiological protection and dissipates heat from the fuel.

Characterization: The collecting of information necessary to evaluate suitability of a region or site for geologic disposal

Colloidal particles: (and **colloidal transport and filtration**) Colloidal particles are usually smaller than 1 micrometer (μm) in diameter and under many conditions can remain in suspension in water indefinitely without settling. They may then be transported at about the same velocity as groundwater;

but are sometimes filtered out when the water moves though the small pores of a rock, such as through the matrix pores of a tuff.

Complex: A species formed by the association, usually of a positive and a negative ion (or ions), both of which may be dissolved, or one of which may be on a solid surface. (See **surface complexation model**). For example, UO_2CO_3 is a dissolved complex formed by association of uranyl ion (UO_2^{2+}) and carbonate ion (CO_3^{2-}).

Container: A receptacle designed to hold spent fuel or radioactive material to facilitate movement and storage

Coprecipitation: The precipitation of a dissolved, usually trace, substance with and in a precipitate formed of major dissolved species, for example, the coprecipitation of uranium with a ferric oxide solid

Decision analysis: A structured approach whose aim is to enhance the decision-making process. It includes a logical decomposition of the problem, the solicitation of expert judgment, means for working out internal inconsistencies in these judgments, and the explicit treatment of uncertainties. Intuitively it can be thought of as "a formalization of common sense for decision problems which are too complex for informal use of common sense" (R. Keeney 1982).

Disposal: The isolation of radioactive materials from the accessible environment with no foreseeable intent of recovering them. Isolation occurs through a combination of constructed and natural barriers, rather than by human control. The Nuclear Waste Policy Act of 1982 specifies emplacement in mined geologic repositories.

Disqualifying geologic feature: A feature that, if present on the site, would eliminate the site from further consideration for development as a repository

Drift: A near-horizontal, excavated passageway through the earth

Engineered barrier system (EBS): The component of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. It includes the radioactive waste form, radioactive waste containers, material placed over and around such containers, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.

Exploratory facility: An underground opening and structure constructed for the purpose of site characterization

Exploratory shaft facility (ESF): An exploratory facility defined in the Site Characterization Plan consisting primarily of two adjacent shafts

Fault: A plane in the earth along which differential slippage of the adjacent earth has occurred

Fault displacement: Relative movement of two sides of a fault such as that which occurs during an earthquake

Fission product: A nuclide produced by the fission of a heavier element

Folding: A curving or bending of a planar structure, such as rock strata or bedding planes. A fold is usually a product of deformation.

Fracture: Any break in a rock (i.e., a crack, joint, or fault), whether or not accompanied by displacement

Geologic block: That portion of Yucca Mountain in which placement of the proposed repository site is being considered

Geologic repository: A system, requiring licensing by the Nuclear Regulatory Commission, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

Ghost Dance Fault: A near vertical north-south trending fault that crosses the eastern side of the Yucca Mountain geologic block

Ground motion: The vibratory movement of the ground caused by earthquakes. It is often characterized in terms of acceleration, velocity, or displacement.

Groundwater table: The upper surface of the zone of water saturation in rocks, below which all connected interstices and voids are filled with water

High-angle joint and fault system: A system of near-vertical joints and faults

High-level waste (HLW): (1) Irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid waste have been converted

Holocene epoch: That period of geologic time extending from 11,000 years ago until the present

Host rock: The rock in which the radioactive waste will be emplaced; specifically, the geologic materials that will directly encompass and be in close proximity to the underground repository

Human factors engineering: A technical discipline that applies what is known about human psychological, physiological, and physical limitations to the design and operation of systems to enhance safety

Igneous activity: The emplacement (intrusion) of molten rock (magma) into material in the earth's crust or the expulsion (extrusion) of such material onto the earth's surface or into its atmosphere or surface water

Illite: A clay mineral that is less sorbent of metal ions and radionuclides than are the smectite clays (see **smectite**)

Inclined dry-drilling: Drilling (at an angle) in which rock and cuttings are lifted out of a borehole by a current of air, rather than a drilling fluid

Infiltration: The flow of a fluid into a solid substance through pores or small openings; specifically, the movement of water into soil or porous rock

Interim storage or storage: Temporary storage of high-level waste with the intention and expectation that the waste will be removed for subsequent treatment, transportation, and/or isolation

Isotope: A class of atomic species, of a given element, having differing atomic weights but identical atomic numbers and slightly differing chemical and physical properties

Isotopic exchange: A reaction in which a specific isotope of an element distributes itself between two or more substances. For example, carbon-14 (C-14 or ^{14}C) tends to distribute itself by the isotopic exchange between the carbon of CO_2 (gas) and the carbon of the mineral calcite ($CaCO_3$).

K_d (distribution coefficient): Mass of species being sorbed on the solid phase, per unit mass of the solid phase, divided by concentration of species being sorbed in solution. Normally reported in milliliters per gram (ml/g).

Low-level (radioactive) waste: Radioactive material that is neither high-level radioactive waste, spent nuclear fuel, transuranic waste, nor byproduct material as defined in Section 11a(2) of the Atomic Energy Act of 1954. Examples include contaminated medical waste, which cannot be disposed of in the garbage.

Metric ton: 1,000 kilograms; about 2,205 pounds

Monitored retrievable storage facility: A facility to collect spent fuel in a central location, where it can be stored until the fuel can be accepted at a repository

Natural analogue: See **analogue**

Near field: The region where the natural hydrogeologic system has been altered by the excavation of the repository or the thermal environment created by the emplacement of high-level waste

Nevada Test Site (NTS): A geographic area located in southern Nevada that is owned and operated by the U.S. Department of Energy and devoted primarily to the underground testing of nuclear devices

Nonwelded tuff: A tuff that has not been consolidated and welded together by temperature, pressure, or a cementing mineral

Performance allocation: The process whereby components of the proposed repository system are assigned expected quantified levels of performance

Performance assessment: Any analysis that predicts the behavior of a system or a component of a system under a given set of constant or transient conditions. In this case, the system includes the repository and the geologic, hydrogeologic, and biologic environment.

Postclosure: The period of time after the closure of the repository

Preclosure: That time prior to the backfilling of the repository

Quality assurance (QA): The management process used to control and assure the quality of work performed

Quaternary period: The second part of the Cenozoic Era (after the Tertiary) beginning about 2 million years ago and extending to the present

Rd (retardation coefficient): Equals the average linear velocity of the groundwater divided by the velocity of the midpoint of the concentration profile of the retarded constituent

Radiation-induced corrosion: A corrosion process that is initiated or controlled by chemical species that are produced by irradiation

Radiometric age dating: The calculation of the age of a material by a method that is based on the decay of radionuclides that occur in the material

Radionuclide: An unstable radioactive nuclide that decays toward a stable state at a characteristic rate by the emission of particles or ionizing radiation(s)

Radionuclide migration: The measurable or predictable movement of radionuclides, generally by liquids or gases, through a rock formation

Repository: A site and associated facilities designed for the permanent isolation of high-level radioactive waste and spent nuclear fuel. It includes both surface and subsurface areas, where high-level radioactive waste and spent nuclear fuel-handling activities are conducted.

Repository horizon: A particular geologic sequence or layer where radioactive waste is intended for disposal. The Yucca Mountain repository horizon is 900 to 1,200 feet beneath the surface of the mountain.

Reprocessing: The process whereby fission products are removed from spent fuel and the fissionable parts are recovered for repeated use

Risk: Possibility of suffering harm or loss due to some event. The magnitude of the risk depends on both the probability of occurrence of an event and the consequences should the event occur.

Rock matrix: The solid framework of a porous rock

Saturated rock: A rock in which all of the connected interstices or voids are filled with water

Seismicity: (i.e., seismic activity) The worldwide, regional, or local distribution of earthquakes in space and time; a general term for the number of earthquakes in a unit of time

Sensitivity analysis: The process of varying an independent variable in a calculation and observing the relative effect on the final answer

Shaft: A near-vertical opening excavated in the earth's surface

Site characterization: See **characterization**

Smectite: A group of clay minerals that are generally strongly sorbent of metal ions such as Mg^{2+} and also of radionuclide cations (positively charged ion)

Sorption: The deposition or uptake of radionuclides or other species from gas or solution onto geologic materials (e.g., granite, basalt, tuff)

Sorption characteristics: Attributes exhibited by rocks and minerals that affect the deposition and/or uptake of radionuclides or other species on their surfaces

Spent nuclear fuel: An irradiated fuel element not intended for further use in a nuclear reactor

Stratigraphic evidence: Evidence obtained through the analysis of the form, distribution, composition, and properties of layered rock

Subsurface water: All water beneath the land surface and surface water

Surface complexation model: There are several surface complexation models. Such models describe the sorption of dissolved species on the surfaces of minerals or other solids. The sorption process is modeled as if it involved the formation of complexes between the dissolved species and surface sites on the solid.

Systems safety: A technical discipline that provides a life-cycle application of safety engineering and management techniques to the design of system hardware, software, and operation

Tectonic features and processes: Those features (e.g., faults, folds) and processes (e.g., earthquakes, volcanism) that are related to the large-scale movement and deformation of the earth's crust

Thermal zone: Those regions of the repository where temperature has been increased by the presence of high-level waste

Transuranic waste (TRU): Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, per gram of waste with half-lives greater than 20 years, except for (1) high-level radioactive wastes, (2) wastes that the U.S. Department of Energy with the concurrence of the Environmental Protection Agency Administrator, has determined do not need the degree of isolation required by 40 CFR 191, or (3) wastes that the U.S. Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61. Research on disposal of TRU is underway at the Waste Isolation Pilot Project (WIPP) in Carlsbad, New Mexico.

Tuff: A rock composed of compacted volcanic ash. It is usually porous and often relatively soft.

Unsaturated rock: A rock in which some or all of the connected interstices or voids are filled with air

Unsaturated zones: Rock/geologic formations that are located above the regional groundwater table

Volcanism: The process by which molten rock and its associated gases rise from within the earth and are extruded on the earth's surface and into the atmosphere

Waste canister: A metal vessel for consolidated spent fuel or solidified high-level waste. Before emplacement in the repository, the canister may be encapsulated in a disposal container.

Waste package: The waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container

Welded tuff: A tuff that has been consolidated and welded together by heat, pressure, and possibly the introduction of cementing minerals

Zeolites: (zeolite minerals) A large group of white, faintly colored, or colorless silicate minerals characterized by their easy and reversible loss of water or hydration, their ready swelling when heated, and their high adsorption capacity for dissolved metal ions in water. They primarily occur in basalts and tuffs.

$^{14}CO_2$: Carbon dioxide containing the radioactive isotope of carbon, ^{14}C

Period List of Elements Showing Atomic Number, Symbol, Element

1	H	Hydrogen	27	Co	Cobalt	53	I	Iodine	79	Au	Gold
2	He	Helium	28	Ni	Nickel	54	Xe	Xenon	80	Hg	Mercury
3	Li	Lithium	29	Cu	Copper	55	Cs	Cesium	81	Tl	Thallium
4	Be	Beryllium	30	Zn	Zinc	56	Ba	Barium	82	Pb	Lead
5	B	Boron	31	Ga	Gallium	57	La	Lanthanum	83	Bi	Bismuth
6	C	Carbon	32	Ge	Germanium	58	Ce	Cerium	84	Po	Polonium
7	N	Nitrogen	33	As	Arsenic	59	Pr	Praseodymium	85	At	Astatine
8	O	Oxygen	34	Se	Selenium	60	Nd	Neodymium	86	Rn	Radon
9	F	Fluorine	35	Br	Bromine	61	Pm	Promethium	87	Fr	Francium
10	Ne	Neon	36	Kr	Krypton	62	Sm	Samarium	88	Ra	Radium
11	Na	Sodium	37	Rb	Rubidium	63	Eu	Europium	89	Ac	Actinium
12	Mg	Magnesium	38	Sr	Strontium	64	Gd	Gadolinium	90	Th	Thorium
13	Al	Aluminum	39	Y	Yttrium	65	Tb	Terbium	91	Pa	Protactinium
14	Si	Silicon	40	Zr	Zirconium	66	Dy	Dysprosium	92	U	Uranium
15	P	Phosphorus	41	Nb	Niobium	67	Ho	Holmium	93	Np	Neptunium
16	S	Sulfur	42	Mo	Molybdenum	68	Er	Erbium	94	Pu	Plutonium
17	Cl	Chlorine	43	Tc	Technetium	69	Tm	Thulium	95	Am	Americium
18	A	Argon	44	Ru	Ruthenium	70	Yb	Ytterbium	96	Cm	Curium
19	K	Potassium	45	Rh	Rhodium	71	Lu	Lutetium	97	Bk	Berkelium
20	Ca	Calcium	46	Pd	Palladium	72	Hf	Hafnium	98	Cf	Californium
21	Sc	Scandium	47	Ag	Silver	73	Ta	Tantalum	99	Es	Einsteinium
22	Ti	Titanium	48	Cd	Cadmium	74	W	Wolfram	100	Fm	Fermium
23	V	Vanadium	49	In	Indium	75	Re	Rhenium	101	Md	Mendelevium
24	Cr	Chromium	50	Sn	Tin	76	Os	Osmium	102	No	Nobelium
25	Mn	Manganese	51	Sb	Antimony	77	Ir	Iridium	103	Lw	Lawrencium
26	Fe	Iron	52	Te	Tellurium	78	Pt	Platinum			

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