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

FROM THE
NUCLEAR WASTE TECHNICAL REVIEW BOARD

May 1991

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
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May 29, 1991

The Honorable Thomas S. Foley
Speaker of the House
United States House of Representatives
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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.

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,



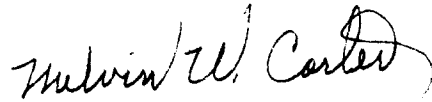
Don U. Deere, Chairman



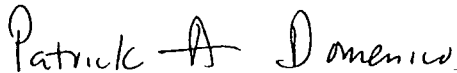
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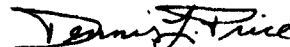
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Executive Summary

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 re-

pository 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, non-technical 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 tech-

nical 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 reposi-

tory. 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 clarifi-

cation, 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 rate-payers. 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 socio-economic 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 geoen지니어ing 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 ex-

hibit 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 management 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.

* 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.

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 re-

lated 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 $^{14}\text{CO}_2$) 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 environment. In roughly decreasing importance, these

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

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 (K_d '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 $K_d > 50$ (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 K_d 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 K_d values greater than 50 in minimum-sorbing rock units, and that the only radionuclides likely to show less retardation (lower K_d '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 K_d values will be selected from the published literature. For example, an extensive summary table of retardation coefficients (R_d 's) and K_d 's for radionuclides sorbed by tuff units from Yucca Mountain is given by Meijer (1990). However, if the lowest (non-zero) K_d 's in the table are assumed to represent conserva-

tive 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 K_d 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, K_d 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" K_d values, unless these data have as been properly measured and reported. To be meaningful, K_d 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 (K_d 's) for performance assessment. A conservative K_d for a particular radionuclide would be one that had been measured using waters from which sorption was minimal onto minerals or tuff units, themselves ex-

hibiting 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, re-

view, and planning between DOE managers and scientists involved in related disciplines in the program. The DOE should, however, implement a program-wide 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 opportu-

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

* 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.

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 Kärnbränsle 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 unforeseen 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 di-

mensions, 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.