U.S. Nuclear Waste
Technical Review Board

Report to
The U.S. Congress and
The Secretary of Energy

Board Activities for the Period
January 1, 2013 – December 31, 2015

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

October 2016

The Honorable Paul D. Ryan
Speaker
United States House of Representatives
Washington, DC 20515

The Honorable Orrin G. Hatch
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Ernest Moniz
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Ryan, Senator Hatch, and Secretary Moniz:

Congress created the U.S. Nuclear Waste Technical Review Board in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) (Public Law 100-203) to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy to implement the Nuclear Waste Policy Act. In accordance with provisions of the NWPAA directing the Board to report its findings and recommendations to Congress and the Secretary of Energy, the Board submits this *Report to the U.S. Congress and the Secretary of Energy*. The Report summarizes Board activities, conclusions, and recommendations for the period, January 1, 2013, through December 31, 2015.

During the period covered by the Report, the Board focused its review on activities undertaken by the U.S. Department of Energy (DOE) to implement its 2013 *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste.* The Board also evaluated DOE activities related to the treatment and conditioning of spent nuclear fuel and high-level radioactive waste managed by DOE.

The Board hopes that Congress and the Secretary will find the information in this summary report useful and looks forward to continuing its ongoing technical and scientific review of DOE activities related to nuclear waste management and disposal.

Sincerely,

Rodney C. Ewing
Chairman

U.S. Nuclear Waste Technical Review Board

U.S. Nuclear Waste Technical Review Board Staff

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Executive Summary

The U.S. Nuclear Waste Technical Review Board (Board) was established by Congress in Title V of the 1987 Nuclear Waste Policy Amendments Act. Its mandate is to "evaluate the technical and scientific validity" of actions taken by the U.S. Secretary of Energy to implement the Nuclear Waste Policy Act (NWPA) as amended. Among other things, Congress charged the Board with assessing the Department of Energy's (DOE's) site characterization activities and activities relating to packaging and transporting high-level radioactive waste (HLW) and spent nuclear fuel (SNF).

The Board is an independent federal agency within the executive branch. Members of the eleven-person Board serve part time and are appointed by the president from a list of nominees prepared by the U.S. National Academy of Sciences. The Board is required to report its findings, conclusions, and recommendations to Congress and the Secretary of Energy at least twice each year. This report summarizes the Board's activities beginning on January 1, 2013, and ending on December 31, 2015.

All the letters, testimony, reports, and meeting materials referred to in this report can be found on the Board's website: www.nwtrb.gov. Many of those documents also are reproduced as appendices to this report. In addition, in June 2015, the Board began streaming its meetings over the Internet; those webcasts are archived on the Board's website.

Background

In January 2013, DOE issued *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*, its response to the recommendations from the Blue Ribbon Commission on America's Nuclear Future. That document outlined DOE's plans to establish an integrated system for the long-term management of HLW and SNF. Among the initiatives that DOE intended to pursue were the following:

- Conducting generic research into potential repository host rocks, including salt, granite, and clay/shale;

- Investigating the deep borehole concept for disposing of certain types of HLW and SNF;
- Evaluating the option for constructing a separate repository that might be used to dispose of certain DOE-managed HLW and SNF; and
- Developing a transportation system to move HLW and SNF from generating sites to either a consolidated interim storage facility or a repository.

In addition to these new projects, DOE continued ongoing efforts to manage its HLW and SNF currently stored in Washington State, Idaho, South Carolina, Colorado, and New York.

Board Activities

Consistent with its legislative mandate, the Board maintained a "watching brief" over technical and scientific aspects of these new initiatives, as well as over the more standard and traditional studies and investigations that DOE has undertaken in the past. During the period covered in this document, the Board published eight reports, held six public meetings, conducted two technical workshops, provided testimony and comments to two congressional committees, and carried out two study trips abroad.[1]

Board Reports

One of the primary means by which the Board communicates its findings, conclusions, and recommendations on the technical and scientific validity of DOE activities and related issues is via written reports to the U.S. Congress and the Secretary of Energy.

- *Review of U.S. Department of Energy Activities to Preserve Records Created by the Yucca Mountain Repository Project*. (NWTRB 2013c)
- *Deep Borehole Disposal of Spent Nuclear Fuel and High-Level Waste*. (NWTRB 2013b)
- *Summary of the Workshop Issues Identified*. (NWTRB 2014b)
- *A Report to the U.S. Congress and the Secretary of Energy: Board Activities for the Period January 1, 2008-December 31, 2012*. (NWTRB 2014a)
- *Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel*. (NWTRB 2015c)
- *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Overview and Summary*. (NWTRB 2015b)
- *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis*. (NWTRB 2015a)

[1] This report does not discuss the Board's 2014 summary report to Congress and the Secretary of Energy (NWTRB 2014a). Although published in January 2016, the Board's analysis, *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program* (NWTRB 2016), is discussed in this report.

- *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program*. (NWTRB 2016)

Board Meetings and Correspondence with DOE

The Board held six public meetings at which DOE and its contractors presented their technical and scientific work related to implementing the NWPA. In accordance with established practice and to ensure the timeliness of Board comments, after every public Board meeting, the Board sends follow-up correspondence to DOE, including observations and recommendations on DOE's work presented at the meetings. Together with Board reports and congressional testimony, the letters represent a substantial body of technical and scientific information and a record of key issues related to the U.S. program for managing and disposing of SNF and HLW.

The six meetings along with the subject manner they covered are listed below. In the body of this report, the reader will find a description of those meetings and a summary of the follow-up letters the Board sent to DOE.

- Waste Form and Disposal Issues: Richland, Washington (April 16, 2013)
- DOE Research and Development Related to SNF and HLW Management: Washington, DC (November 20, 2013)
- DOE Research and Development Related to Salt as a Geologic Medium for Disposal of SNF and HLW: Albuquerque, New Mexico (March 19, 2014)
- DOE SNF and HLW: Idaho Falls, Idaho (August 6, 2014)
- DOE-Managed HLW and SNF at the Savannah River Site: Augusta, Georgia (October 29, 2014)
- Transportation of Commercial SNF: Golden, Colorado (June 24, 2015)

Board-Sponsored Technical Workshops

From time to time over the years, a particular technical topic became so central to DOE's waste-management program that the Board organized a technical workshop to explore the subject in depth. During the period covered by the document, the Board conducted two technical workshops. The first, held November 18–19, 2013, in Washington, DC, examined the impact of dry-storage canister design on the future handling, storage, transportation, and disposal of SNF. The workshop brought together eight experts from DOE, DOC contractors and laboratory scientists, nuclear industry representatives from the United States and abroad, and representatives from nongovernmental organizations. The Board issued a report summarizing the issues identified at this workshop (NWTRB 2014b).

The second technical workshop, held October 20–21, 2015 in Washington, D.C., focused on DOE's efforts to evaluate the deep borehole disposal concept. Twenty-seven experts from DOE, DOE contractors and laboratory scientists, the U.S. Geological Survey, the U.S. Defense Nuclear Safety Board, and the U.S. Environmental Protection Agency, university researchers, and independent consultants participated. The Board issued a report containing its findings, conclusions, and recommendations (NWTRB 2016).

Board Testimony and Correspondence with Congress

An important aspect of the Board's peer-review responsibilities involves advising decision-makers in Congress and the Administration on technical and scientific issues associated with SNF and HLW management and disposal. In addition to issuing reports, the Board fulfills this responsibility by providing testimony on nuclear waste issues at the request of congressional committees. During the period covered by this report, the Board provided testimony to the House Appropriations Subcommittee on Energy and Water Development (NWTRB 2013a). Also, the Board provided comments on draft legislation circulated by the Senate Energy and Natural Resources Committee (Ewing 2013b).

Interactions with the Interested Public

A fixture of all Board meetings is the public comment session, where interested members of the public are invited to comment on and ask questions about the information presented at the meetings. In addition to providing the Board with the most recent and relevant information on DOE's nuclear waste activities, the meetings offer a unique forum for the interested public to interact directly with the Board and its staff; DOE managers, scientists, engineers, and consultants; and other program participants. Comments made at the meetings and other submitted materials are included in the meeting records on the Board's website: www.nwtrb.gov.

Board Interactions with Radioactive Waste-Management Programs Abroad

Since its inception, the Board has interacted in various ways with radioactive waste-management and disposal programs in other countries. The objective of these interactions has been to gain knowledge and perspective from the relevant experiences of these programs in order to enhance the Board's technical and scientific evaluation of DOE activities. During the period covered by this report, delegations of Board members and staff visited Sweden, France, Switzerland, and Belgium. In addition, a small delegation of Board members and staff visited the People's Republic of China.

Preface

Congress established the U.S. Nuclear Waste Technical Review Board as part of the 1987 Nuclear Waste Policy Amendments Act, to "evaluate the technical and scientific validity" of the actions taken by the Secretary of Energy to implement the Nuclear Waste Policy Act.

This report provides a summary of the activities carried out by the Board between January 1, 2013, and December 31, 2015. Among those activities are findings, conclusions, and recommendations adopted by the Board in its letters and reports. This report records the views of the Board *at the time* they were published.

Board Activities

The Board and Its Mission

The U.S. Nuclear Waste Technical Review Board (Board) was established by Congress in Title V of the 1987 Nuclear Waste Policy Amendments Act (NWPAA). Its mandate is to "evaluate the technical and scientific validity" of actions taken by the U.S. Secretary of Energy to implement the Nuclear Waste Policy Act (NWPA) as amended. Among other things, Congress charged the Board with assessing the Department of Energy's (DOE's) site characterization activities and activities relating to packaging and transporting high-level radioactive waste (HLW) and spent nuclear fuel (SNF).

The Board is an independent federal agency within the Executive Branch. Members of the eleven-person Board serve part time and are appointed by the President from a list of nominees prepared by the U.S. National Academy of Sciences. For the period covered by this document, the members of the Board who served were: Dr. Rodney C. Ewing (Chairman), Dr. Jean M. Bahr, Dr. Steven M. Becker, Dr. Susan L. Brantley, Dr. Susan B. Clark, Mr. Allen G. Croff, Dr. Efi Foufoula-Georgiou, Dr. Gerald S. Frankel, Dr. Linda K. Nozick, Dr. Kenneth L. Peddicord, Dr. Paul J. Turinsky, and Dr. Mary Lou Zoback.[2] Biographies of the members can be found in Appendix A.

The Board is required to report its findings, conclusions, and recommendations to Congress and the Secretary of Energy at least twice each year. This report summarizes the Board's activities beginning on January 1, 2013, and ending on December 31, 2015.[3] All the letters, testimony, reports, and meeting materials referred to can be found on the Board's website www.nwtrb.gov. Many of those documents also are reproduced as appendices to this report. In addition, in June 2015, the Board began streaming its meetings over the Internet; those webcasts are archived on the Board's website.

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[2] Dr. Sue Clark served from July 28, 2011, until Ocotber 31, 2014. Mr Allen Croff replaced her on February 23, 2015.

[3] This report does not discuss the Board's 2014 summary report to Congress and the Secretary of Energy (NWTRB 2014a). Although published in January 2016, the Board's analysis, *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program* (NWTRB 2016), is discussed in this report.

Recent Developments in Nuclear Waste Management

In passing the NWPAA, Congress instructed DOE to limit its efforts to identify a site for a deep-mined, geologic repository to Yucca Mountain in Nevada. In January 2002, based on a recommendation from Secretary of Energy Spencer Abraham, President George W. Bush informed Congress of his intention to select this site. Overriding the objections from Nevada Governor Kenneth Guinn, Congress ratified the president's decision in July 2002.

In June 2008, DOE submitted an application to the Nuclear Regulatory Commission (NRC) for a license to construct a repository at Yucca Mountain. In January 2010, however, the administration of President Barack Obama initiated steps to halt DOE's licensing effort, maintaining that the Yucca Mountain Project (YMP) was "unworkable," and DOE soon after attempted to formally withdraw the application before the NRC. In September 2011, the commissioners were divided on whether to take the action of overturning or upholding the Atomic Safety and Licensing Board (ASLB) decision denying DOE's petition. At the same time, however, the commissioners, in recognition of budgetary limitations, directed ASLB to complete all necessary and appropriate activities, including disposition of all matters currently pending before it (NRC 2011). Accordingly, ASLB suspended the proceedings (ASLB 2012).

In August 2013, the U.S. Court of Appeals for the District of Columbia Circuit ruled that NRC had to continue its licensing process using remaining appropriated funds of approximately $11.1 million.[4] As part of that work, the NRC staff in 2015 released volume three of its Safety Evaluation Report (SER), which evaluated repository safety after permanent closure. The NRC staff concluded in that volume of the SER that DOE had complied with all of the relevant health and safety regulations, with the exception of requirements regarding ownership of land and water rights. At that time, the staff recommended that a construction license not be granted because DOE had not met the ownership requirements, and a supplement to DOE's environmental impact assessment had not yet been completed (NRC 2015). Although the staff continued its YMP-related activities, without the appropriation of additional funding by Congress, those efforts are likely to end soon. As of December 31, 2015, approximately $1.8 million in unobligated funds remained available.

In parallel with seeking to withdraw the license application in 2010, President Obama instructed the then Secretary of Energy, Steven Chu, to establish a Blue Ribbon Commission on America's Nuclear Future (BRC). The group was charged with recommending a new strategy for managing the back end of the nuclear fuel cycle. In a report issued in January 2012, BRC made several important recommendations (BRC 2012).

- Adopt a new consent-based approach to siting both consolidated storage facilities not at reactor sites and deep-mined, geologic repositories.
- Establish a new independent organization to implement the waste-management program.
- Pass legislation that would facilitate access to fees deposited in the Nuclear Waste Fund, independent of the annual appropriations process.

[4] In re Aiken County, 725 F.3d 255 (DC Cir. 2013).

- Initiate prompt efforts to develop a new geologic disposal facility.
- Initiate prompt efforts to develop one or more consolidated storage facilities.
- Prepare early on for eventual large-scale SNF and HLW transport to consolidated storage and disposal facilities.

In January 2013, DOE issued its response to BRC's recommendations, *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* (DOE 2013). Although many details of implementation were left to future discussions with lawmakers and other interested and affected parties,

> the Administration endorses the key principles that underpin the BRC's recommendations. The BRC's report and recommendations provide a starting point for this Strategy, which translates many of the BRC's principles into an actionable framework within which the Administration and Congress can build a national program for the management and disposal of the nation's used nuclear fuel and high-level radioactive waste (DOE 2013, 1).

A discussion draft on "Comprehensive Nuclear Waste Legislation," which was intended to implement at least some of BRC's advice, was released by the Senate Committee on Energy and Natural Resources on April 25, 2013. A hearing on S. 1240, the "Nuclear Waste Administration Act of 2013," was held in July 2013.

DOE subsequently advanced three initiatives from its *Strategy*, each of which had been considered by BRC. The first followed up on a BRC evaluation into whether some DOE-managed HLW and SNF should be disposed of in a repository separate from a repository for commercial SNF (and the remaining DOE-managed HLW and SNF). In March 2015, DOE issued *Report on Separate Disposal of Defense High Level Radioactive Waste* (DOE 2015c). Revisiting the decision made by President Ronald Reagan in 1985 to develop a single repository for both defense and commercial HLW and SNF, the report reevaluated the six factors identified in Section 8(b)(1) of the NWPA.[5] Noting that significant changes had taken place over the past three decades in repository availability, approaches for siting disposal facilities, the end of the Cold War, and new environmental obligations, DOE concluded that "a strong basis exists to find that a Defense HLW repository is required" (DOE 2015c, iv). In a memorandum to the Secretary of Energy, Ernest Moniz, President Obama determined that a separate defense HLW repository was in fact "required" under the terms of the NWPA (Obama 2015). That determination broadened the authority DOE already held under the Atomic Energy Act to dispose of defense SNF in a deep-mined, geologic repository.

The second initiative responded to BRC's recommendation favoring

> further RD&D to help resolve some of the current uncertainties about deep borehole disposal and to allow for a more comprehensive (and conclusive) evaluation of the potential practicality of licensing and deploying this approach, particularly as a dis-

[5] These include cost efficiency, health and safety, regulation, transportation, public acceptability, and national security.

> posal alternative for certain forms of waste that have essentially no potential for re-use (BRC 2012, 30).

Supported by a report from Sandia National Laboratories (SNL; SNL 2015), DOE issued a request for proposal for vendors to conduct a deep borehole field test (DOE 2015a).

Consent-based siting of nuclear waste storage and disposal facilities was the subject of DOE's third initiative. In a *Federal Register* notice, DOE stated that it was implementing

> a consent-based siting process to establish an integrated waste management system to transport, store, and dispose of commercial spent nuclear fuel and high-level defense radioactive waste. In a consent-based siting approach, DOE will work with communities, tribal governments, and states across the country that express interest in hosting any of the facilities identified as part of an integrated waste management system. (DOE 2015b, 79,872)

Subsequently, DOE scheduled a kickoff meeting in Washington, DC, and eight additional meetings across the country to obtain public comments on five questions:

1. How can DOE ensure that the process for selecting a site is fair?
2. What models and experience should DOE use in designing the process?
3. Who should be involved in the process for selecting a site, and what are their roles?
4. What information and resources do people think would facilitate their participation?
5. What else should be considered?

Fulfilling its obligations under the NWPAA, the Board maintained a "watching brief" over technical and scientific aspects of these initiatives, as well as over the more standard and traditional studies and investigations that DOE has undertaken in the past.

Board Review of DOE's Preservation of Records Created by the Yucca Mountain Project

DOE's investigation of the Yucca Mountain site through its Office of Civilian Radioactive Waste Management (OCRWM) and its subsequent development of a license application development generated massive amounts of technical and scientific information, as well as extensive analyses of that information. As they are public records, proper archiving and preservation of those materials are required by the Federal Records Act.[6] In addition, the possibility remains that the Yucca Mountain license application might be revived in the future. Finally, the data gathered, the samples collected, and the analyses undertaken by

[6] Records include all books, papers, maps, photographs, machine-readable materials, or other documentary materials, regardless of physical form or characteristics, made or received by an agency of the United States government under federal law or in connection with the transaction of public business and preserved or appropriate for preservation by that agency or its legitimate successor as evidence of the organization, functions, policies, decisions, procedures, operations, or other activities of the government or because of the informational value of the data in them (44 USC. § 3301). Many of the key terms, phrases, and concepts in this statutory definition of records are defined in 36 C.F.R. 1222.12.

the YMP could prove to be of independent scientific value beyond their relevance in supporting an application to construct a deep-mined, geologic repository at Yucca Mountain. On July 29, 2010, responsibility for archiving and preserving Yucca Mountain scientific and engineering information was internally transferred from OCRWM to the Office of Legacy Management (LM; OCRWM 2010). On September 30, 2010, OCRWM ceased all of its activities.

As part of the Board's ongoing technical and scientific review of DOE activities toward implementing the NWPA, the Board began to monitor events as they unfolded in the spring of 2010, considering, among other things, the question of what would become of the materials developed for the Yucca Mountain license application. DOE recognized the importance of properly archiving and preserving critical information from the YMP. DOE also appreciated how the decision to cease work on the YMP and the effort to withdraw the license application had created an environment where DOE's management of YMP-generated information might be closely scrutinized by other interested and affected parties. For this reason, DOE approached the Board in May 2010 and proposed that the Board, as an independent party, formally oversee LM's efforts to archive and preserve YMP documents and materials. At that time, DOE notified ASLB that it was in discussions with the Board about how it might carry out that task (DOE 2010). The following year, in a report accompanying the Fiscal Year 2012 Energy and Water Development Appropriations Bill, the House Appropriations Committee directed the Board to "give support to" DOE as it archived and preserved scientific data, documents, and materials from the YMP (HR 2012).

LM's primary responsibility in this respect is to archive and preserve materials created by the YMP during its nearly 30-year lifetime. These materials take the form of electronic databases and retrieval systems, analytical software, and physical objects such as maps, videotapes, well-logs, and other items, some of which cannot be digitized. The two most important databases and retrieval systems are the records information system (RIS) and the e-mail warehouse. The former holds the central information generated by the YMP; the latter stores the Lotus Notes e-mails that were sent and received by YMP personnel. Together, these databases and systems contain more than two million records.

Additional physical items—such as geologic cores, rock samples, and experimental materials like metal coupons from corrosion investigations—are not the responsibility of LM but instead are the responsibility of DOE's Office of Nuclear Energy (DOE-NE). Preserving these physical materials falls outside DOE's request to the Board to oversee LM activities. Because these items are an important component of the scientific information produced by the YMP, however, the Board also considered how those materials were being preserved.

LM also is responsible for implementing DOE's commitment, made in the President's Budget for Fiscal Year 2011 and later confirmed to ASLB, to archive and preserve a special collection of records, DOE's Licensing Support Network Document Collection (LSNdc), which contains 3.65 million documents totaling more than 34 million pages of information. Until early August 2011, this material could be accessed through a web-based, NRC-operated portal, the Licensing Support Network, which was developed to facilitate the legal process of discovery during the license application proceeding.

Figure 1. Storage box for YMP documents.

Although there is considerable overlap between the internal YMP records and the LSNdc, one is neither a subset nor a superset of the other. The internal YMP databases hold confidential information, such as attorney–client communications, litigation work products, and "housekeeping" requirements. The LSNdc contains copyrighted documents and other materials that, while relevant to DOE's license application, were not created by the YMP.

As part of its review, the Board designed a spot-checking exercise to determine whether records could be retrieved from storage (NWTRB 2013c,9–10). It is important to state precisely the limitations of this exercise. Given the vast number of records archived and preserved, the Board could only ask LM to retrieve a very small fraction of the documents. The Board requested records spanning a wide range of technical work undertaken over the years by the YMP, but this does not represent a statistically significant sampling of the documents archived and preserved.

Based on the results of its review, including the spot-checking retrieval exercise, the Board found that (NWTRB 2013c):

1. *Yucca Mountain documents have been preserved and can be accessed and retrieved.* LM developed a computer program that integrates the primary electronic database, the RIS, with records of data collected during the course of the YMP. In the Board's view, this new system, the Yucca Mountain Record Information System (YMRIS), significantly improved the functionality of search and retrieval operations. In particular, the Board has a high degree of confidence that documentary material the YMP developed and included in the LSNdc can be accessed and retrieved.

2. *With significant time and effort, LM personnel can search and retrieve e-mails from the e-mail warehouse.* Because of the level of effort involved, the Board could not directly test LM's capability to access electronic messages. Board staff members, however, were shown how LM responded to congressional requests for YMP e-mails. A small set of e-mails deemed necessary to support the hearing on the Yucca Mountain license application was captured in the RIS database and included in the LSNdc. Board staff members were able to readily access a sample of these messages through the YMRIS.

3. *LM does not have the capability to load and execute most analytical software.* This software was used by YMP personnel to analyze data and support modeling activities. LM cannot run most of the analytical software to re-create some of these analyses, although both the inputs and outputs used by the software have been archived and preserved.

4. *Some boxes LM stored contain physical objects, such as videotapes, well logs, and maps. However, LM has only a general understanding of the boxes' contents.* When activity ceased on the YMP, OCRWM personnel began transferring boxes with physical objects to LM for storage. The contents of those boxes were inventoried, and the inventories were provided to LM. The amount of detail in the inventories varies greatly. For this reason, it is unclear what measures might be needed to preserve the physical objects from the YMP for extended periods or to provide searchable databases for these objects.

5. *LM used schedules approved by the National Archives and Records Administration (NARA) to identify YMP records that should be preserved permanently and YMP records that should be preserved temporarily—that is, for periods ranging from 10 to 100 years.* LM will hold temporary records. Permanent records will be transferred to NARA no sooner than 30 years from the time that the YMP is conclusively shut down, either as the result of a non-appealable court decision or by definitive executive or legislative actions. The procedures NARA used to allow public access to the records under its control can be cumbersome; thus, examining even permanent YMP records may be difficult in the future.

6. *The general public can access written records LM holds.* However, to do so, individuals or organizations must file a Freedom of Information Act request. During the time the Board was conducting its review (2011–2013), LM had received only four such requests from external parties since it took over responsibility for archiving and preserving YMP-generated material.

Based on its findings, the Board made the following recommendations:

- *A retrieval exercise, similar to the one conducted in August 2012, should be repeated in three years to assess the level of record preservation and retrieval capability at that time.*
- *Policymakers should evaluate the priority given to archiving and preserving YMP documents and physical materials. Without a continuing commitment of resources, it is unclear whether the current level of effort in this area can be sustained over time.*
- *Additional project documents may still be forwarded to LM to be archived and preserved. Those records should be added to the YMRIS if they contain new technical information.*
- *DOE should consider providing web access to the foundational documents developed as part of the YMP. These records may be of scientific, technical, and historical value, and deserve to be easily accessible by the general public.*
- *In the cases of boxes of physical objects stored by LM for which inventories are limited and/or not included in a searchable database, DOE policymakers should evaluate whether to undertake additional efforts to develop informative inventories that could be placed into searchable databases.*
- *Although not the responsibility of LM, materials from geologic investigations—for example, rock cores and materials from experimental studies, such as metal coupons used in corrosion investigations—may have future value to ongoing DOE projects and may even find application in broader scientific and technical studies. This report does not address or evaluate the fate of these materials; however, the Board recommends that*

an external review be initiated to determine what types of materials exist, where they are located, and what their potential value might be. A review should provide recommendations to DOE policymakers on whether and how materials judged to be valuable should be preserved and made accessible.

Board Review of DOE's Activities Related to Repository Development

DOE Research and Development on Spent Nuclear Fuel and High-Level Radioactive Waste Management

DOE's Office of Nuclear Energy (DOE-NE) supports a broad range of scientific and technical analyses that are directly relevant to DOE's responsibility to manage both commercial and defense HLW and SNF. The research explores topics ranging from waste form behavior, which dictates the source term that drives repository performance, to alternative disposal concepts and factors affecting preclosure operations. As part of the Board's mandate to provide ongoing review of those studies, it invited key investigators or their DOE-NE sponsors to discuss this research. At a public meeting on November 30, 2013, in Washington, DC, the Board heard presentations about studies undertaken in two DOE-NE units, the Office of Used Fuel Disposition R&D (research and development) and the Office of Fuel Cycle R&D. In a January 29, 2014, letter, the Board provided comments on the presentations and made a series of recommendations (Ewing 2014d).

Important developments over the past decade include decisions by nuclear power plant owners to irradiate the fuel in their reactors for a longer time in order to improve the economics of reactor operations. Increasingly, fuel is discharged from reactors at burnup levels greater than 45 gigawatt days per metric ton of uranium. Such material is termed "high-burnup" SNF. Very little data are available to project how high-burnup SNF behaves if it is stored for decadesA technical specialist from Argonne National Laboratory described studies of high-burnup fuel cladding..[7]

These investigations produced some preliminary data. For example, the tests were restricted in scope and size, were spread over a broad range of environmental conditions, and were not repeated to understand statistical variations. In the Board's view, these circumstances limit the test results' usefulness in predicting changes in cladding performance during transport after extended storage. The researcher informed the Board that he was working with the nuclear industry, which has a substantial amount of data on high-burnup fuel characteristics. These data, however, are proprietary and not currently accessible to DOE.

- *DOE should consider both how it can extend the work it is supporting in this area—for example, by conducting more tests using cladding samples irradiated in research reactors, to study the impact of high burnups—and how it can gain access to the results of work done in this area by other national and international R&D programs.*

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[7] Cladding contains the fuel pellets within the fuel rod and can act as an engineered barrier within a repository.

- *Given the importance of understanding how high-burnup fuel and cladding properties could change during prolonged SNF storage, DOE should focus particular effort on gaining access to more data from the nuclear industry about this issue.*

A senior DOE manager from the Office of Used Fuel Disposition R&D discussed the High Burnup Dry Storage Cask Research and Development Project (CDP), which is jointly sponsored with the Electric Power Research Institute (EPRI). This effort is intended to provide much-needed data on changes in the properties of high-burnup SNF and potential degradation of storage system materials during extended storage. Although the Board strongly supports this research, it is concerned that cask monitoring over time will be too limited. Moreover, it is unclear whether there will be available DOE facilities where the cask can be opened to inspect the SNF at the conclusion of the ten-year project.

- *DOE should make it a priority to develop a more extensive program to inspect and examine, using advanced analytical techniques, the condition of SNF with a range of designs, burnups, and storage histories, to establish the capability to open large dry-storage casks and canisters in a dry facility.*
- *DOE should increase its R&D efforts to develop sensors and instrumentation that can operate in the extreme environments that exist in storage systems, so that additional data on the condition of SNF and dry-storage systems can be collected over long storage periods.*

Two scientists from SNL reported on a major study conducted by experts from ten DOE program offices and national laboratories, three universities, and a DOE contractor. The study was designed to evaluate how different disposal concepts might be suitable for the full inventory of commercial and defense HLW and SNF (SNL 2014). The concepts included disposal in a deep-mined, geologic repository constructed in salt, clay/shale, and crystalline host rock, and disposal in deep boreholes. Collectively, the investigators sorted the HLW and SNF into ten categories.

Although this effort appeared to be comprehensive, the Board concluded that the waste form/disposal options evaluation was based on qualitative metrics and appeared not to have addressed a number of issues: (1) temperature dependence of corrosion rates and mechanisms for different waste forms, (2) matching waste forms to geochemical conditions to improve waste form performance, and (3) matching waste form performance to the half-life and radiotoxicity of different waste streams.

- *Perhaps a useful and objective approach to improving this evaluation would be to analyze in more detail the results available in other countries: Sweden for granite, France and Switzerland for clay, and Germany for salt. It would have been more interesting to compare the performance assessment results for each of the different geologies for a single waste form (most important, SNF).*

Figure 2. Disposal of spent nuclear fuel in a clay formation.

- *Given the considerable effort that went into assessing an unsaturated site in volcanic tuff at Yucca Mountain, DOE should include the relevant results from that work in the current evaluation to increase the study's range.*
- *DOE should make the SNF and HLW inventory data available to the public in a more accessible format—for example, in spreadsheet form.*

Based on presentations made at this meeting and DOE published documents available at the time, DOE's position on the potential use of deep borehole disposal was not clear. The senior DOE manager described DOE's R&D program to develop deep borehole disposal technology and suggested it may be used to dispose of both SNF and HLW. The SNL presentations, however, indicated that DOE's waste form and disposal options evaluation implied that emplacing SNF and HLW at depths of from 3 to 5 kilometers (km) beneath the surface is not operationally feasible because of the size of the disposal containers. The options and waste form study concluded that deep borehole disposal would not be possible for large waste packages (e.g., existing vitrified HLW containers and commercial SNF in dual-purpose canisters) and, in other cases, that significant modification of waste forms would be required (e.g., rod consolidation for SNF or redesign of canisters for HLW).

- *Prior to embarking on an expensive, full-scale demonstration, it would be prudent to have an explicit understanding of the types of waste that are realistic candidates for deep borehole disposal.*
- *If DOE envisions that deep borehole disposal might be appropriate for some small-volume, "niche" waste, then any borehole research program should be designed with disposal of that waste form in mind and justified on the basis of a cost–benefit and safety analysis.*

A senior manager from the Office of Fuel Cycle R&D provided an overview of his unit, including its mission, near-to-long-term program objectives, and R&D activities on materials recovery and waste forms. It was not clear from his presentation how DOE establishes R&D priorities to allocate its limited funding in this area. For example, the presentation on developing the technology for uranium separation from seawater was technically interesting but, given the significant challenges facing DOE (e.g., investigating how the characteristics of high-burnup SNF change during extended periods of dry storage) as well as the abundance of uranium that is readily available for extraction using conventional technologies at reasonable cost, it is difficult for the Board to understand why separating uranium from seawater should be a high priority.

- *DOE's Fuel Cycle Technologies R&D program should establish its priorities based on work needed to provide information on the most important issues related to managing and disposing of SNF and HLW.*

DOE Research and Development Activities on Salt as a Geologic Medium for SNF and HLW Disposal

On March 19, 2014, the Board held a public meeting in Albuquerque, New Mexico. The main topic of interest was DOE's R&D activities on salt as a potential host rock for disposing of SNF and HLW.

A 1957 report from a panel convened by the National Academy of Sciences initially identified salt as a promising host rock for a deep-mined, geologic repository (NAS 1957).[8] As originally articulated, the salt disposal concept appears elegant in its simplicity. If the salt is there, then water flow—the predominant mechanism for transporting waste to the biosphere—is probably not occurring at rates of concern for waste disposal. Ideally, under lithostatic pressure the salt itself moves slowly, closing around emplaced disposal packages and healing any fractures or voids that may have formed during the repository construction phase. In the salt disposal concept, robust and long-lasting waste packages are not considered necessary to isolate and contain HLW and SNF; the hydrogeologic environment is key to long-term repository performance.

Starting in the early 1960s in the United States, Oak Ridge National Laboratory investigated bedded salt in the Permian basin. The world's first deep-mined, geologic repository (for defense-origin transuranic waste) at the Waste Isolation Pilot Plant (WIPP) in New Mexico is carved out of bedded salt. Of the nine locations DOE chose as "potentially acceptable" repository sites, seven were in salt formations.[9] Beginning in the early 1970s, the German waste management program focused on salt as the preferred disposal medium. Extensive experiments were conducted at two sites in Lower Saxony, Asse, and Gorleben.

At the public meeting, the Board heard from seven DOE and DOE laboratory scientists, who discussed DOE's generic research on salt as a geologic medium for the disposal of HLW and SNF. The modeling and laboratory studies explored a range of issues that would need to be addressed before a repository could be developed in that host rock, including:

- Alternatives for emplacing and backfilling waste packages within the mined-out tunnels (drifts).
- Simulating coupled thermal-hydrological-mechanical processes.
- Brine migration by the movement of fluid inclusions up the thermal gradient.
- Developing performance-assessment models for a salt repository.

In none of the presentations, however, did the scientists explore in detail the implications for repository performance.

Alternatives for emplacing and backfilling waste packages within the mined-out tunnels (drifts): Since the late 1950s, in situ studies conducted in the United States and Germany have examined the behavior of salt domes and bedded salt as a potential host rock. An

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[8] Both bedded-salt formations and salt domes could host a repository.

[9] NWPA Section 116(a) [42 USC 10136].

investigator from SNL in his presentation to the Board summarized the relevant scientific literature. He maintained that available data have been well developed for most repository design options. However, for one alternative—emplacing waste packages horizontally on the drift floor, along with the use of crushed salt to backfill the drift—important data gaps remain.

Emphasizing the importance of obtaining that missing data, a DOE official from the Carlsbad Field Office, which oversees WIPP, noted that heater tests conducted in the 1980s at WIPP indicated that emplacing packages containing HLW and SNF vertically in boreholes drilled in the drift floor could cause a steep and very localized temperature and pressure gradient to form and caused brine to flow into the cavity. Horizontal emplacement, along with a crushed salt backfill, not only could avoid that problem but also could be operationally easier to implement.

Simulating coupled thermal-hydrological-mechanical processes: Waste packages generate heat that declines over time, but early on, heat can affect, among other things, the porosity, permeability, thermal conductivity, solubility, and water vapor pressure of a salt formation. All of those alterations can influence the long-term performance of a deep-mined, geologic repository.

In two presentations to the Board, an investigator from Los Alamos National Laboratory (LANL) and a second one from SNL discussed simulations they executed. The LANL study employed the Finite Element Heat and Mass transfer code to look at the impact of placing five waste packages on the drift floor covered by run-of-mine salt backfill. At higher decay heat levels (more than 250 watts/package), a boiling region was created, resulting in a boiling region near the packages and water vapor moved upward away from the packages. The vapor eventually condenses into water that dissolves the salt and flows back toward the packages, where salt deposits build up as the water again boils and salts reprecipitate.

The SNL presentation focused on the value of a second simulation model, SIERRA, a family of finite-element, multiphysics codes. In collaboration with a German team of investigators, the SNL team is comparing current constitutive models and simulation procedures for exploring thermo-mechanical behavior and healing in salt formations. Although that work is still at the preliminary stage, the SNL investigator maintained that the applicability of the SIERRA model appears promising.

Brine migration by the movement of fluid inclusions up the thermal gradient: A second scientist from LANL discussed his research that explored free fluid migration in single salt grains. He concluded that temperatures in crushed and intact salt drop very rapidly away from the heat source. Further, the rate of migration is influenced by the size of the fluid inclusion and by the temperature gradient in the salt. Finally, the brine becomes enriched in pure salt as it migrates toward the heat source, depositing magnesium-rich salt along the migration channels.

Developing performance-assessment models for a salt repository: Under the regulatory regime now in place in the United States, deep-mined, geologic repository developers must demonstrate compliance with health and safety rules, using a formal technique known as performance assessment. Two other researchers from SNL described efforts to fashion a generic evaluation for a repository constructed in a salt formation.

The first presentation focused on what information and process understanding would be needed to develop a multiphysics performance assessment that relies on high-performance computing architecture and software. The researcher described a salt-reference case and identified key events, features, and processes that would have to be considered. The capabilities of this performance assessment model were illustrated by examining radionuclide transport for the scenario of an undisturbed repository.

The second presentation described how ongoing collaboration between investigators in the United States and Germany contributed to an improved understanding of how a repository built in a salt formation might evolve over time. Among the topics being studied are the isochoric deformation of salt, triaxial strength tests, salt creep and consolidation, and in situ analogues.

Based on these presentations, in a letter to Dr. Peter Lyons, Assistant Secretary for Nuclear Energy, and to Mr. David Huizenga, Senior Advisor for Environmental Management, the Board advanced a set of findings and recommendations (Ewing 2014c).

- *DOE should develop a framework for bringing together the different modeling groups, to encourage model comparison, integration, and computational performance improvement, which are essential elements for further advances in understanding coupled processes and in increasing confidence in these models for repository site performance evaluation.*
- *DOE should continue its efforts on coupled-process model validation using published laboratory and in situ field-scale test data.*
- *DOE should pay better attention to potential disadvantages associated with locating a repository for SNF and HLW in salt (inadvertent human intrusion, brine migration along clay seams, and accelerated plastic flow of salt due to the presence of heat-generating waste) in order to ensure a balanced evaluation of the performance of salt as a medium for a deep-mined, geologic repository.*
- *DOE should collect in situ data applicable to emplacing waste packages on drift floors and backfilling using crushed salt.*
- *DOE should make relatively simple calculations of the amount of water that might accumulate around a waste package due to fluid inclusion migration within the thermal gradient of a waste package.*
- *DOE should continue its efforts in model improvement, including incorporation of thin clay beds that can have significant impact on mechanical performance, and, most important, its efforts in model validation using field data available from U.S. and international sites.*
- *DOE should include human intrusion and ingress of water from sources external to the salt body in its performance-assessment analysis of SNF and HLW disposal in salt.*

- *DOE should use information on the flooding that has occurred at the Asse site (in Germany) to evaluate lessons that can inform the consideration of salt as a geologic medium for SNF and HLW disposal.*
- *DOE should evaluate whether the operational advantages of emplacing waste packages on drift floors and backfilling with crushed salt would have any adverse impacts on the long-term performance of an SNF and HLW repository in salt.*

Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel

The 1982 NWPA called for a presidential determination about whether developing a repository solely for disposing of radioactive waste from the nuclear weapons complex was "required" and defined six factors (cost efficiency, health and safety, regulation, transportation, public acceptability, and national security) to be considered in making this determination.[10] Based on a DOE evaluation of the need for separate repositories, President Ronald Reagan determined in 1985 that defense HLW should be disposed of in a common repository with commercial SNF.

As noted above, the BRC recommended that DOE evaluate whether separate repositories should be developed for disposal of at least some DOE-managed HLW and SNF on the one hand and commercial SNF (and the remaining DOE-managed HLW and SNF) on the other.[11] The administration's strategy, articulated in 2013, promised to undertake that evaluation.

In October 2014, DOE issued a report, *Assessment of Disposal Options for DOE Managed High-Level Radioactive Waste and Spent Nuclear Fuel* (DOE 2014). The report recommended implementing a strategy for disposal of some DOE-managed HLW and SNF in a separate deep-mined, geologic repository rather than disposal of these wastes in a repository commingled with commercial HLW and SNF. The report also recommended that DOE retain the flexibility to consider options for disposal of smaller DOE-managed waste forms in deep boreholes rather than in a deep-mined, geologic repository. In a document released in March 2015, *Report on Separate Disposal of Defense High-Level Radioactive Waste* (DOE 2015c), DOE revisited the six factors identified in the NWPA that are used to determine whether separate disposal of defense HLW is required. Although the report on separate disposal is primarily an analysis to support a presidential decision on whether to develop separate repositories, it also examines some of the associated technical issues. On March 24, 2015, President Barack Obama issued a Presidential Memorandum that stated, "the development of a repository for the disposal of high-level radioactive waste resulting from atomic energy defense activities only is required" (Obama 2015).

Developing a separate repository for defense HLW represents a fundamental shift in policy for managing radioactive waste in the United States. In addition, as DOE observed in the report on separate disposal, DOE retains its authority under the 1954 Atomic Energy Act to construct a repository that would be used exclusively to dispose of both defense HLW

[10] NWPA Section 8(b).

[11] Commenting on the BRC report in an April 2012 letter to DOE, the Board noted that the issue of commingling waste "is a technical issue that deserves consideration (Garrick 2012)."

and SNF as well as of HLW and SNF from DOE's R&D activities. Although this authority may be open to conflicting legal interpretations, the Board's consideration of the technical and scientific questions that might arise if DOE pursues this new approach presumes that at least some DOE-managed SNF may be disposed of in a "defense-only" repository (NWTRB 2015c). In this report, the Board identified a number of technical and scientific issues that should be addressed as DOE implements this new approach, including those stemming from waste form performance, DOE SNF degradation and release rates, repackaging of naval SNF for disposal, and disposal of DOE-managed HLW and SNF in deep boreholes.

Based on its review, the Board made the following recommendations.

- *DOE should consider waste form performance in different host-rock types after degradation of the waste package in future assessments. Much information can be obtained initially by looking at the performance of commercial SNF and vitrified HLW in different host-rock types.*
- *DOE should develop a better understanding of the degradation rates of DOE SNF in potential repository geologic environments, particularly the DOE SNF types that could contribute most to radionuclide release and calculated dose, to improve the basis for the separate repository safety assessment.*
- *DOE should evaluate approaches, benefits, and costs of repackaging cooler naval SNF into smaller disposal packages.*
- *DOE should conduct research on borehole sealing technology and assess whether more robust engineered barriers might be required for disposal of selected waste forms in deep boreholes.*

Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel

Every country that has chosen a strategy for managing its HLW and SNF over the long term has opted for disposal in deep-mined, geologic repositories. Depending on the available lithology, a nation may be able to adopt one or more disposal concepts—designs for a repository system composed of the host-rock formation and engineered barriers—to isolate the HLW and SNF from the accessible environment.

As the discussion at the beginning of this report makes clear, the issue of repository siting has dominated recent developments in nuclear waste management in the United States. Should the proposed repository at Yucca Mountain be put back on the table? Should a consent-based siting strategy be developed for the first or second repository? Should a separate repository for DOE-managed HLW and SNF be constructed?

In order to provide useful information to policymakers faced with such decisions and to aid the public with an increased understanding of the issues, the Board wrote two reports on selecting a site for a deep-mined, geologic repository for HLW and SNF (NWTRB

2015a, 2015b).[12] The reports present a historical analysis of 24 instances in ten countries where implementers such as DOE attempted to find a repository site.

The reports rest on the premise that finding a repository site is a difficult *socio-technical challenge*. Many levels of government exercise power. Affected constituencies strive to make their voices heard, often with the goal of preventing the development of a repository; sharp disagreements over values and how they are weighed arise. Scientific and engineering uncertainties may be difficult, if not impossible, to resolve.

The reports rest as well on the premise that finding a repository site requires the metaphorical passage, generally more than once, of possible locations through two filters, a Technical Suitability Filter and a Social Acceptability Filter. The reports describe how the Technical Suitability Filter is established, typically by implementers through formal rules or regulations collectively termed "site-suitability criteria." Depending on how many disposal concepts might be adopted and the order in which sites pass through the two filters, three types of site-suitability criteria can be distinguished. *Host-Rock-Specific Criteria* are disposal concept–specific and typically identify quantitative rock properties that would indicate that a repository developed at a particular location would perform satisfactorily. *Generic Criteria* are typically used to compare a site in one lithology with a site in a completely different lithology. Finally, *Exclusion Criteria* identify certain geologic characteristics that almost automatically preclude developing a facility. They also inform communities interested in exploring the possibility of hosting a repository whether the local geology is likely to pass muster. The type of criteria used by the implementer can strongly influence how it winnows down prospective settings to potential sites, to candidate sites. Consequently, how interested and affected parties perceive and understand the implementer's action is also affected by the type of criteria.

The Social Acceptability Filter can take many forms, including referenda, mass action, negotiated agreements, and legislative determinations. Passage through it can result in a range of outcomes, including a willingness to host a repository, taking a wait-and-see stance, or protests based on poor technical analyses or flawed procedures. Increasingly, nations have created consent-based siting processes. These also take a variety of forms, depending on who consents, how consent is granted, and at what point consent can be withdrawn. Although consent-based processes have resulted in selecting a site in some countries, in others such processes failed.

Although passage through one filter can mostly be described and understood independently of passage through the other, the two are interdependent in several respects. Examples of this interdependence include: simplicity of the disposal concept and social acceptability; the order in which a possible site passes through one or the other of the filters; political influences in determining site-suitability criteria; technical ambiguity, bureaucratic discretion, and social trust; support or opposition to nuclear energy production and attitudes toward radioactive waste management; and technical uncertainty and informed consent.

[12] NWTRB 2015b provides a summary of the Board's views about designing a siting process; NWTRB 2015a provides the empirical evidence upon which those views are based.

As the reports detail, experience siting a deep-mined, geologic repository has been mixed. Of the two dozen attempts in nine nations that have taken place over the years, six are still on track; of the four sites selected, applications for construction authorization are active in three. Notwithstanding this history, the Board strongly agrees with the international consensus within the scientific and engineering communities and among implementers and regulators that developing such a facility is technically feasible and provides a compelling level and duration of protection.

Figure 3. Investigation into the properties of crystalline rock. Photo courtesy of SKB.

Thus, the Board advises DOE that it should not pursue any strategy that might distract from focused efforts to develop a deep-mined, geologic repository.

Based on the information developed in the two reports, and in keeping with its technical mandate, the Board presents four recommendations that policymakers should consider if they decide to launch a new siting process. These recommendations address the preparation of site-suitability criteria to replace DOE's 1985 *Siting Guidelines* (DOE 1985) and the timing of when a state might object to the president's nomination of a repository site.

The geological diversity in the United States may make it impossible to choose a single disposal concept in advance of the site-selection process; nuclear regulators in Finland and Sweden were able to do so because a single rock type, crystalline rock, underlays virtually all of both countries. Consequently, despite their limitations, Generic Criteria will have to provide the initial foundation for any new set of site-suitability criteria. DOE's 1985 *Siting Guidelines* contain generic criteria that are consistent with international practice and are technically defensible. DOE's 2001 Yucca Mountain–specific site-suitability regulation relies on probabilistic performance assessment (DOE 2001). Putting aside the ongoing debate over the utility and validity of that methodology, using it to winnow down sites is inappropriate and technically questionable. The data needed to employ such an approach sensibly are not available at the earliest stages of any siting effort.

- *DOE's 1985* Siting Guidelines *should be adopted as a sound basis for developing any new rules that might structure a future siting process. DOE's 2001 site-suitability regulation (for Yucca Mountain), which relies on a technically complex performance assessment using detailed site-specific data, does not provide a sound basis for selecting sites in the future.*

DOE applied the 1985 *Siting Guidelines* to compare locations after it reduced the number of prospective settings for the second repository. In that case, all of the sites were in crystalline rock formations. Using generic criteria when host-rock-specific criteria would have sufficed unnecessarily complicates matters. Developing new guidelines should anticipate this situation. Adding host-rock-specific criteria would simplify and make more transparent the technical basis for DOE's decisions in the future.

- *The 1985* Siting Guidelines *should be supplemented with host-rock-specific criteria that are applicable to geology-specific concepts (including relevant engineered barriers) that have been advanced for disposing of HLW and SNF in salt, crystalline rock, or clay/shale formations and their associated environmental settings.*

DOE also used the 1985 *Siting Guidelines* to winnow five potential sites for the first repository down to three. DOE exercised its legitimate discretion to interpret ambiguous language in the rule and to determine how its decision-aiding multiattribute utility analysis methodology should be carried out to distinguish among sites. In both that case and in down-selecting prospective settings for the second repository, charges of unfairness were leveled that could not be dispelled neatly and persuasively. There is a fine line between protecting the discretion required for bureaucratic flexibility and enlarging the domain of discretion to the point where bureaucratic decisions appear unaccountable. If new (or revised) guidelines are written, they must be scrutinized carefully to ascertain on which side of that line they fall. Erring on the side of reducing discretion is a conservative approach, but it is one that is more likely to be viable in the long term.

- *To the greatest extent possible, those responsible for developing any new site-suitability criteria should minimize the ambiguity that facilitates the implementer's discretion in applying them, helping to ensure the objectivity of the process and public confidence in its outcome. If, at any point during the siting process, the criteria need to be changed, the implementer should use a transparent and meaningfully participatory process to do so.*

As siting investigations proceed at the surface and in laboratories, knowledge is gained about the potential performance of a proposed repository system. That knowledge is often supplemented by constructing underground research laboratories in the same hydrogeologic environment as the candidate site or at the candidate site itself. Thus, the chances of scientific and technical surprises arising are reduced even if they cannot be completely eliminated. Generally, communities asked to consent to the site choice are concerned about when a right of withdrawal can be exercised, because disagreements between the implementer and the community may arise over whether any surprises encountered during site investigations can be worked around or whether they automatically disqualify a site. The 1982 NWPA uniquely requires that investigations at depth be completed before a final decision on selecting a repository site can be made. Both the implementer *and* the affected state benefit from investigations carried out at depth where the repository will be built. Resources might not be expended in vain. Giving consent or withholding it until the time of "full disclosure" permits a more informed choice.

- *Any new siting process should preserve the requirement in the 1982 Nuclear Waste Policy Act that a final choice of site await extensive underground characterization.*

Board Review of DOE's Activities Related to the Management of Its High-Level Radioactive Waste and Spent Nuclear Fuel

As part of its technical oversight activities involving disposal of DOE-managed HLW and SNF, the Board closely followed efforts at the five locations where that material is being stored and managed.[13] During the period of January 1, 2013, to December 31, 2015, the Board held meetings and toured facilities at three of those locations: the Hanford Reservation, the Idaho National Laboratory, and the Savannah River Site (SRS).

DOE Research and Development Activities Related to Disposition of Vitrified High-Level Radioactive Waste

On April 16, 2013, the Board held a public meeting in Richland, Washington. The primary purpose of the meeting was to hear from DOE and other experts about R&D efforts on vitrified HLW disposition. In addition, a senior DOE official from the Office of Environmental Management (DOE-EM) discussed his unit's plans to treat the wide variety of radioactive wastes generated at defense-complex sites. The Board also invited a panel of interested and affected parties to discuss critical technical issues dealing with disposal of DOE-managed HLW and SNF now kept at the Hanford Site. A director in DOE-NE informed the Board about the potential for direct disposal of dry storage containers currently in service at nuclear power plant sites. Finally, the Assistant Secretary for Nuclear Energy provided an overview of the Obama Administration's response to BRC's recommendations.

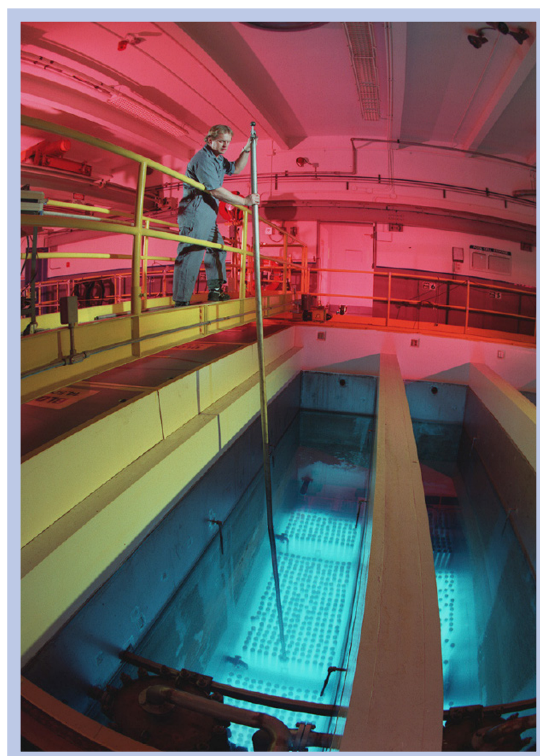

Figure 4. Strontium and cesium capsules stored at Hanford.

What follows below is limited to the Board's evaluation of DOE's R&D activities related to the disposition of vitrified HLW (Ewing 2013a).

A senior scientist from the Savannah River National Laboratory (SRNL) delivered an informative lecture that made the complex chemistry and physics of HLW vitrification understandable to experts and generalists alike. Her presentation segued into a panel discussion that included DOE officials who have experience at three sites that have produced or will produce vitrified HLW: SRS, the West Valley Demonstration Project (WVDP), and Hanford. In addition, a technical expert from the French Alternative Energies and Atomic Energy Commission provided insights into the approach taken to vitrification by the French reprocessing industry.

The lecture and the panel made clear that the process technology employed at SRNL and WVDP differs significantly from the technology being designed for use at Hanford. Nonetheless, lessons can be learned on matters such as feed processing, sampling, and characterization as well as repository waste-acceptance criteria for glass produced complex-wide.

[13] Washington State, Idaho, South Carolina, Colorado, and New York

- *The Board believes strongly that closer collaboration among DOE-EM sites involved in waste vitrification would be mutually beneficial. It recommends increased integration of their programs, possibly including establishing an advisory panel with representation from all three sites, to ensure the relevant experiences and lessons learned at one site are shared with the others.*

A second panel, composed of DOE experts from SRNL and the Pacific Northwest National Laboratory, as well as the director of the Vitreous State Laboratory at the Catholic University of America, commented on DOE's technology development programs on waste forms. Both panels observed that the U.S. strategy for waste vitrification contrasts with that used by the French. Although the U.S. established waste-specification criteria based on standard tests, the French recognized that the performance of glass as a waste form can vary dramatically as a function of the dissolution and release mechanisms within the geochemical/hydrologic environments of different repository rock types.

Research on the mechanisms that influence changes in glass corrosion rates with time is essential to evaluating overall repository performance, as is addressing uncertainties that could affect radionuclide release rates. Coordinated experimental and predictive modeling-simulation programs could be most productive in understanding these mechanisms, particularly in different geologic media.

- *DOE should consider carefully the long-term performance of glass in a variety of geologic environments, as well as the interactions of different types of engineered barriers with the glass. A specific effort also should be made to evaluate and demonstrate the long-term performance of the low-activity glass that DOE-EM plans to dispose of at the Integrated Disposal Facility at Hanford.*

DOE Research and Development Activities Related to the Disposition of Spent Nuclear Fuel

On August 6, 2014, the Board held a public meeting in Idaho Falls, Idaho. It heard from technical experts and officials from DOE-EM and -NE. The meeting's purpose was to continue the Board's evaluation of efforts by DOE to prepare its own and commercial HLW and SNF for disposal. The Board considered three types of issues: those that cross-cut both offices, those that affect only DOE-EM, and those that affect only DOE-NE. The Board communicated its findings, conclusions, and recommendations to DOE in two letters (Ewing 2014a, 2014b).

Issues that cross-cut the Offices of Environmental Management and Nuclear Energy: Before DOE dismantled the YMP in 2010, a clear division of labor had been established between the OCRWM—which was responsible for preparing both commercial SNF and DOE-managed HLW and SNF for transportation and disposal—and DOE-EM's National Spent Nuclear Fuel Program (NSNFP), which oversaw efforts to ensure that DOE-managed SNF met OCRWM's acceptance criteria for disposal at Yucca Mountain. This division of labor not only allocated responsibility clearly between the two units but also guarded against the possibility that some critical function might not fall to either organization.

Subsequently, DOE leaders reassigned many of OCRWM's responsibilities, but one critical function—R&D on the long-term disposition of DOE-managed HLW and SNF—fell between organizational cracks. The need for that R&D is especially acute because, compared with commercial SNF, DOE-managed SNF is more damaged, includes many more types of fuel and cladding, and contains highly enriched uranium, all of which are important considerations when designing and implementing an integrated SNF management and disposal program.

- *DOE should review OCRWM's past responsibilities and functions, and explicitly assign the responsibilities, which have not already been reassigned, to specific DOE organizations to facilitate the management and disposal of DOE-managed SNF and HLW.*

Further, for a variety of reasons, the NSNFP was severely cut back between the time the YMP was shut down and 2014. As a result, interactions among the technical staff across the defense complex were much less frequent, so common issues were harder to identify and address. For example, until 2011, the NSNFP maintained the Spent Fuel Database, which served as the single source of information about DOE-managed SNF.

- *DOE should revitalize the NSNFP to integrate approaches at the staff level, address issues affecting the DOE-managed SNF program, and update and maintain the Spent Fuel Database.*

The issue of HLW and SNF transportation also illustrates how OCRWM's closure led to a loss of the crucial link between different waste types and transportation strategies. OCRWM was responsible for designing, obtaining regulatory approval for, and fabricating the transportation cask system for all HLW and SNF (except the Navy's) destined for Yucca Mountain. Work in this area on commercial SNF is being conducted within DOE-NE, but the corresponding responsibilities for DOE-EM's HLW and SNF have not been assigned.

- *DOE should explicitly assign responsibility for the coordination of all transportation activities for HLW and SNF.*

In the Board report (NWTRB 2013c), the focus was on preserving records created by OCRWM for the YMP; it did not explicitly address subordinate records created at DOE field offices responsible for managing HLW and SNF. Although the Board has not undertaken a systematic evaluation of the record preservation and retrieval practices at field office sites, comments made during the meeting suggest that some information may no longer be available from official documents. This material, which contains information about the radionuclide content and details about packaging, would have eventually been transmitted to OCRWM as part of the waste-acceptance process. Several DOE-EM presentations at the August 6, 2014, Board meeting required retrieving information on past DOE operations; the presenters indicated that this was a difficult task.

- *DOE should assess the level of record preservation and retrieval of DOE field office site organizations and ensure that all records related to past HLW and SNF management are preserved and retrievable to support future waste management activities.*

Given the transfers and retirements that have taken place since 2010, the possibility cannot be excluded that the valuable knowledge base, including experiences, related to past SNF handling operations and other management activities has already been lost.

- *DOE should take early action to capture this critical knowledge so it can be used to support later DOE efforts aimed at handling wastes, certifying transportation and storage packages, and undertaking interim storage and final disposal.*

Issues that affect only the Office of Environmental Management: DOE-EM manages a wide variety of SNF. Many advantages could be secured if it were possible to emplace all or most of that SNF into a standard canister, which could be loaded into a transportation cask. An engineer from the Idaho National Laboratory (INL) discussed the design, regulatory, and development obstacles that stood in the way of creating a standardized canister. A contractor working at Hanford described the design for a multicanister overpack and how it has been loaded, mostly with N-Reactor SNF (and debris). The multicanister overpack also would have to be loaded into a transportation cask to ship the SNF off site. The contractor remarked that evaluations of some issues, such as criticality and the availability of certified commercial transportation casks, still needed to be performed.

- *DOE should resume efforts on the DOE standard canister and multicanister overpacks. These efforts should include:*
    - *Resolve criticality issues related to the transportation and disposal of the DOE standard canister. These efforts should include submitting a topical report to NRC to confirm that the standard canister would be acceptable to the NRC staff as part of a transportation package based on the canister's ability to prevent water intrusion under hypothetical transportation accident conditions.*
    - *To the extent that DOE continues its generic disposal research, it should assess the viability of and implications for disposal of the DOE standard canister and multicanister overpacks in different geologic settings with their associated disposal concepts (e.g., copper outer layer for a waste package in a reducing environment).*
    - *Identify those issues that could affect future shipment of the multicanister overpacks from Hanford to a geologic repository.*

DOE's decision to terminate the YMP broadly affected management of the HLW and SNF under DOE's control. Among other things, those wastes will have to be stored at defense-complex sites for longer than expected. Three such impacts were discussed at the meeting.

First, a major force driving DOE SNF management at INL is the 1995 Settlement Agreement negotiated between DOE, the U.S. Navy, and the state of Idaho. It requires DOE to remove all SNF from wet storage by December 31, 2023, and from the state of Idaho by January 1, 2035, with some exceptions for SNF being maintained for purposes of testing. A 2008 addendum to the 1995 Settlement Agreement, related only to the receipt and storage of naval SNF at INL, provided additional exceptions to the 2023 and 2035 SNF deadlines. The 1995 Settlement Agreement also requires HLW that existed at the time of the agreement to be treated so that it is ready to be transported out of Idaho for disposal by 2035.

Because of the uncertainty surrounding the prospects for final disposition of HLW and SNF, designs for a facility to package DOE-EM–managed SNF for off-site transportation cannot be finalized. For example, the NRC-licensed, but unconstructed, Idaho Spent Fuel Facility might need to be modified to accommodate packaging operations.

- *Regarding the plans for SNF management at Idaho, DOE should review and update the scope of the proposed packaging facility, taking into account the possibility that some SNF could be stored at the site beyond 2035. DOE should examine how this extended period of storage could impact the capabilities needed and the timing for packaging the SNF.*[14]

Second, significant differences exist across the DOE-EM complex in terms of how the issue of aging management is being addressed. For example, at the Hanford Site, almost all of the SNF has been cleaned, dried, sealed in new multicanister overpacks, and stored in a new facility. At INL, however, most of the SNF storage facilities are more than thirty years old. Some of the SNF—with the exception of the material in the NRC-licensed Three Mile Island Unit 2 Independent Spent Fuel Storage Installation—is not stored in an inert environment, and SNF degradation is not monitored.

- *DOE should develop a comprehensive systemwide strategy for managing aging SNF and SNF storage facilities and individual aging management plans for all types of SNF and SNF facilities. The systemwide strategy should be based on the expected period of storage and should take advantage of the experience of the NRC's aging management programs.*

Third, the longer SNF has to be stored, the more critical becomes the issue of how well it has been dried prior to being placed in storage containers. Water in a sealed SNF canister can interact with the SNF over time and can potentially create a flammable gas mixture, cause gas pressurization, and lead to container and fuel corrosion. Adequate drying of SNF, especially degraded SNF, during multipurpose canister packaging is necessary to ensure safe interim storage and subsequent transport and disposal.

- *DOE should collect additional empirical data to develop an understanding of the important processes that can occur—during drying and afterward—in a sealed container with SNF that may not have been effectively dried.*

Issues affecting only the Office of Nuclear Energy: The 1995 Settlement Agreement also affects DOE-NE SNF stored in pools. A DOE manager from INL described how transferring this material into dry storage presents significant challenges. The Board recognizes the national importance of the Advanced Test Reactor to nuclear research and to the production of cobalt-60 for medical applications. The Board supports DOE's plans to keep operating that facility beyond 2023.

- *DOE should assess the implications of the future generation and storage of SNF from the Advanced Test Reactor beyond 2023 on DOE's proposed packaging facility.*

Increasingly, nuclear utilities in the United States and abroad are leaving fuel in reactors for longer periods. Little data are available to understand how such "high-burnup" fuel might degrade over time as it is stored. DOE and the nuclear utilities are conducting research designed to fill in at least some of these information gaps. The Board believes that this work is of great importance.

[14] The Board made an identical recommendation in Ewing 2014a.

- *DOE should become more active in international efforts to develop a better understanding of the changes in fuel and cladding characteristics during extended periods of dry storage so that it can benefit from shared results of other R&D programs.*
- *As DOE reviews and updates the scope of the proposed packaging facility, it should consider the infrastructure that may be needed to support DOE's R&D efforts on high-burnup SNF and to periodically examine the commercial SNF that is currently in dry storage at Idaho National Laboratory.*

A DOE official described his unit's R&D program for "accident-tolerant" fuels. Although generally pleased with that effort, the Board recommended that:

- *In addition to evaluating the performance in the reactors of "accident-tolerant" fuels, DOE should also evaluate how these fuels will perform during extended dry storage and subsequent transportation and disposal.*

Management and Plans for Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste Stored at DOE's Savannah River Site

On October 29, 2014, the Board held a public meeting in Augusta, Georgia. Based on the information presented at the meeting, the Board was impressed with the way DOE and its contractors at the SRS have been successful in integrating operations at the facilities on site, including processing SNF, removing and vitrifying HLW from underground tanks, and storing vitrified HLW in preparation for off-site disposal in a geologic repository. The Board's specific findings, conclusions, and recommendations were conveyed to DOE-EM (Ewing 2015b).

The Board's long-standing concern about DOE's efforts to integrate the elements of its waste management system was addressed by the first speaker, a senior DOE-EM official. He provided an update to an earlier DOE-EM presentation on establishing a DOE SNF corporate board and reestablishing a tank waste corporate board (Ewing 2014b, 2–3). The former unit would bring together representatives of DOE program offices— for example, DOE-NE, Office of Science, and Naval Reactors. The latter would be composed of managers from the different DOE-EM sites.[15]

- *Regarding HLW management and coordination between the DOE sites, DOE should place more emphasis on exchanging lessons learned and transferring new technology, such as improvements in HLW melter performance and advances in melter designs. The Board suggests that this may be an appropriate role for the tank waste corporate board.*

More generally, the Board envisioned a wide range of constructive activities that might be undertaken by the two corporate boards.

- *DOE should task the SNF corporate board and the tank waste corporate board with:*
    - *Employing a systems engineering approach to developing and implementing SNF and HLW management programs.*

[15] The Board is not aware of the activities that either of these boards has undertaken since 2015.

    - *Obtaining design and regulatory input from outside organizations whose activities will impact the technical management of DOE SNF and HLW within the DOE complex and its preparation for off-site transportation (e.g., NRC, state regulators, local government organizations in the vicinity of the DOE sites, and commercial cask vendors).*
    - *Ensuring that DOE's efforts to transport and dispose of HLW, defense SNF, and commercial SNF are integrated both at the management level and at the staff level.*
    - *Making DOE's efforts to integrate these activities more transparent.*

One of the earliest facilities that reprocessed defense SNF is H-Canyon; L Basin stored some of the SNF in water while it awaited treatment. Both remain in operation and will continue to do so for the foreseeable future. To avoid problems experienced at Hanford, where SNF significantly degraded when stored in water, a robust program for SNF surveillance is crucial. Assessing and controlling SNF degradation in L Basin is especially important because all of it may not be reprocessed in H-Canyon. This residual fuel will have to be handled, dried, and packaged for disposal at a geologic repository. DOE has initiated an Augmented Monitoring and Condition Assessment Program at L Basin, but some necessary actions have not yet been undertaken.

- *DOE should accelerate the Augmented Monitoring and Condition Assessment Program to substantiate the condition of the fuel and to facilitate future SNF handling, drying, and packaging operations.*

In addition to monitoring potential SNF degradation in L Basin, the structure of the basin itself needs to be evaluated as it becomes increasingly close to reaching the end of its design life. DOE undertook that assessment and concluded that the condition of L Basin would allow SNF storage there for another fifty years. The Board is pleased that this assessment included seismic hazard analyses and relevant ground-motion modeling.

- *DOE should consider further actions to validate the structural integrity of L Basin, including:*
    - *Obtaining and analyzing core samples of the L Basin structural concrete, including samples containing rebar.*
    - *Expanding visual examination of the interior and exterior surfaces of the basin walls, including those areas that are in contact with soils.*
    - *Obtaining and analyzing core samples of older (possibly on the order of one hundred years) representative concrete from other sources to gather data that can improve understanding of the concrete's long-term performance.*
    - *Ensuring coordination with other efforts to study concrete aging, such as those being conducted by the DOE Light Water Reactor Sustainability Program, the Concrete Sustainability Hub at the Massachusetts Institute of Technology, and the DOE-EM Cementitious Barriers Partnership at Vanderbilt University.*

DOE's planning for future operations of both H-Canyon and L Basin is still in flux. The situation is complicated because some of the material stored at SRS—stainless steel– and Zircaloy-clad SNF—cannot be treated in H-Canyon as it is currently configured. DOE committed to process only approximately 3.3 metric tons of the projected 22 metric tons of SNF that is either at or coming to SRS. The effect on repository performance of roughly 19 metric tons of SNF for which no disposition path has been selected would be dwarfed in a combined defense/commercial repository but could be significant in a defense-only facility.

- *DOE should perform a study to compare the performances of DOE SNF and vitrified HLW in different geologic environments. The results of this work should then be used to inform plans for processing SNF in H-Canyon.*

Board Review of DOE's Activities Related to Deep Borehole Disposal

Transmittal Letter to the Department of Energy for the Board's Fact Sheet on Deep Borehole Disposal

As discussed earlier, in 2013, DOE released *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste.* In that document, DOE announced that it was "developing a research and development plan for deep borehole disposal (DOE 2013, 13)." At the Board's public meeting on April 16, 2013, in Richland, Washington, Assistant Secretary for Nuclear Energy Peter Lyons briefly mentioned that that effort was under way.

The Board subsequently prepared a fact sheet, outlining the basic elements involved in implementing deep borehole disposal (NWTRB 2013b). In a July 30, 2013, letter to Dr. Lyons, the Board transmitted the fact sheet to DOE. In the letter, the Board reiterated its position that implementing deep borehole disposal "would not eliminate the need for a deep-mined, geologic repository." Further, "because deep borehole disposal is in the earliest stages of development, significant technological challenges must be resolved" (Ewing 2013d, 1–2). The Board conveyed the following recommendations for DOE to consider as it crafted its R&D plan (Ewing 2013d).

- *There are drilling, casing, and sealing challenges associated with disposing of spent nuclear fuel and high-level waste in deep boreholes. DOE should investigate the different components of the deep (5 km) borehole disposal system (e.g., drilling, emplacement, and sealing) in a logical stepwise sequence, starting at the bench-scale and progressing to in situ tests prior to implementing a full-scale pilot deep borehole.*
- *A major challenge will be characterizing the host rock at great depth. The petrologic, hydrologic, and geochemical characteristics of the rock units at depth may vary considerably. DOE should use international collaborations with those countries that have operating underground research laboratories, such as Switzerland and Sweden, to identify and address issues surrounding characterization of rock at depth and to understand how the heterogeneity of petrologic, hydrologic, and geochemical characteristics could affect drilling, casing, and sealing the proposed borehole drilling systems.*

- *Due to limitations on the size of the package that can be emplaced in a deep borehole, a major challenge will be dismantling spent nuclear fuel assemblies and consolidating the spent nuclear fuel rods into smaller packages. Dismantling and consolidating will require new facilities and entail additional cost and potential exposure of workers. DOE should assess these impacts as part of the deep borehole disposal R&D plan.*

Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program

On October 20 and 21, 2015, the Board held an International Technical Workshop on Deep Borehole Disposal of Radioactive Waste in Washington, DC The purpose was to review the technical and scientific validity of DOE activities assessing the feasibility of using deep boreholes to dispose of some radioactive waste. During the workshop, DOE made presentations on its Deep Borehole Disposal Research and Development Program and its plan for the Deep Borehole Field Test. These talks were followed by presentations by and discussions among U.S. and international experts on relevant aspects of deep borehole disposal of radioactive waste. The discussions were organized into seven panels that addressed the following technical and scientific topics: (1) experience in deep drilling in crystalline rocks, (2) emplacement modes, (3) borehole seals, (4) hydrogeology at depth, (5) geochemistry of fluids at depth, (6) multiple barriers (waste forms and package materials), and (7) efficacy of deep borehole disposal and risk analysis. During the workshop, the Board reviewed specific details of the DOE Deep Borehole Field Test as well as broader issues of the DOE deep borehole disposal concept.

The DOE deep borehole disposal concept envisions disposal of radioactive waste in one or more boreholes drilled to a depth of 5 km (3.1 mi) in crystalline basement rock. The lower 2 km (1.2 mi) of the borehole would be used as the disposal zone, wherein a series of waste packages would be emplaced. The upper 3 km (1.9 mi) of the borehole would then be sealed with bentonite and concrete. The disposal zone in the borehole disposal concept is significantly deeper than in a mined, geologic repository, which is typically 0.5 to 1 km (0.31 to 0.62 mi) deep. The volume and capacity of the disposal zone in a single borehole are, of course, much smaller than in a deep-mined, geologic repository. Waste isolation in the DOE deep borehole disposal concept is based on the assumptions of long radionuclide travel time through the rock to sources of drinking water due to the great distance and the low permeability of the rocks at depth, increasing salinity with depth that would promote stable stratification based on fluid density and prevent the buoyant movement of water upward, and chemically reducing conditions at depth that would decrease the solubility and mobility of some radionuclides. The DOE concept takes very limited credit for engineered barriers, such as waste packages and waste forms, following borehole closure.

DOE identified the following waste forms as potential candidates for deep borehole disposal.

- Cesium and strontium capsules stored at the Hanford Site in Washington State.
- Untreated calcine HLW currently stored at INL.
- Salt wastes from electrometallurgical treatment of sodium-bonded fuels that could be packaged in small canisters as they are produced.

Figure 5. Drill rig for creating deep boreholes.

- Some relatively small DOE-managed SNF currently stored in water-filled pools at the INL and at SRS in South Carolina.

DOE acknowledged that all of the above waste forms also could be accommodated in a deep-mined, geologic repository. However, DOE believes that the deep borehole disposal concept could offer a pathway for earlier disposal of some wastes than might be possible in a mined repository. DOE also indicated that commercial SNF is not being considered for deep borehole disposal, mainly because of its size.

Based on the information presented at the International Technical Workshop, the Board released a report that considered two main questions (NWTRB 2016).

1. What technical and scientific issues may affect the feasibility of the concept of using deep boreholes to dispose of select radioactive waste forms?

2. Will the results obtained from the Deep Borehole Field Test provide the necessary technical and scientific data to support the DOE evaluation of the feasibility of disposing of select waste forms in deep boreholes?

What follows summarizes the Board's findings, conclusions, and recommendations documented in that report.

1. *Disposal of radioactive waste in deep boreholes does not eliminate the need for a deep-mined, geologic repository.* The Board observed that available performance assessments do not indicate any discernible improvement in the long-term safety of geologic disposal of radioactive waste using a deep borehole compared with a mined, geologic repository. Although deep boreholes might provide a disposal option for certain types of DOE-managed waste, all of the waste forms being considered for deep borehole disposal could be disposed of in a mined, geologic repository. Many large waste forms, such as the packages of vitrified HLW of the type being produced at SRS, are not suitable for disposal in deep boreholes, given current technical limits on borehole diameter.

2. *A deep borehole disposal system could be as complex as a mined, geologic repository; assessing the performance of each of these disposal options may require an equivalent level of data collection and testing.* Deep boreholes, however, lack the easy working access for characterizing the disposal zone that shafts, ramps, and tunnels would provide in the case of a much shallower mined, geologic repository. Thus, the ability to characterize the disposal zone in a borehole is extremely limited as compared

with a mined, geologic repository. Also, the Board has not been presented with any compelling evidence that deep borehole disposal can be accomplished more quickly than can disposal in a mined, geologic repository. Both approaches will pass through a lengthy, sequential process of developing regulations, site selection, data acquisition and analysis, licensing, and construction.

3. *DOE runs the risk that information later found to be necessary to support its evaluation of the feasibility of the deep borehole disposal concept at other sites will not have been obtained during the test Deep Borehole Field Test.* The DOE approach to assessing the feasibility of the deep borehole disposal concept is focused on confirming the assumptions underpinning the DOE safety case for the deep borehole disposal concept: long radionuclide travel time to sources of drinking water due to the great distance and the low permeability of the rocks at depth, increasing salinity with depth that would promote stable stratification based on fluid density and prevent the buoyant movement of water upward, and chemically reducing conditions at depth that would decrease the solubility and mobility of some radionuclides. The DOE approach does not fully take account of the potential heterogeneity of the subsurface environment and the complex set of interactions and feedback among the engineering activities related to drilling the borehole, and the conditions of the natural geologic system at depth, nor does it fully consider how data from the potentially complex system at one site can be applied to another.

4. *The operational safety strategy required for drilling and emplacement operations involving radioactive material is very different from that of operations involving non-radioactive material.* Hence, it is important to consider the operational implications and limitations of handling and emplacing actual, highly radioactive waste and how these may be simulated during the Deep Borehole Field Test. The operational implications and limitations presented by handling and emplacing radioactive waste could impact the assessment of the feasibility of deep borehole disposal of radioactive waste.

The presentations made at the International Workshop make clear that substantial time and effort will be required to fully evaluate the concept of deep borehole disposal. In the Board's view, the Deep Borehole Field Test should carefully consider the key parameters and information that would be needed to fully evaluate the feasibility of deep borehole disposal of radioactive waste. This would provide a basis for additional planning, including definition of specific technological and scientific goals, and obtaining a broader range of data, such as those from surface-based characterization methods and those needed to support regulatory interactions, and greatly improve the technical basis and rationale for the DOE Deep Borehole Disposal Program.

Based on its findings, the Board made the following recommendations:

- ***DOE should ensure the drilling program design and implementation are reviewed by experts with extensive experience in drilling and down-hole operations (e.g., logging, testing, well completion) and in designing and operating equipment for handling highly radioactive material.*** *These experts should be independent of the Deep Borehole Field Test contractor and of the lead national laboratory on the project, and should be able to monitor the progress of the project and report on it to the Secretary of Energy.*

- ***DOE should complete a more comprehensive risk analysis for all aspects of the drilling and emplacement** program as part of assessing the feasibility of deep borehole disposal of radioactive waste. In particular, an analysis should be conducted of what options will be available in the event of an accident during waste emplacement and the implications of such an accident for the safety of recovery operations and the isolation of waste. A transparent and comprehensive assessment of the five possible emplacement modes for deep borehole disposal, including their absolute and relative risks for having and recovering from an accident, also should be completed.*

- ***DOE should strengthen its assessment of the feasibility of the deep borehole disposal option by addressing the technical and scientific issues related to the potential heterogeneity of the subsurface geology and the complex in situ conditions at depth.** DOE should take into consideration the potential implications, with a focus on conducting a defensible safety analysis and demonstrating the transferability of the data and results of analysis to other sites. DOE should address these issues in the guidance it provides to the contractor for developing the drilling and test plan. Specifically, the project team should carefully consider the key parameters for the safety case that need to be measured during sampling and testing in the 2- to 5-km (1.2- to 3.1-mi) depth range encompassing the seal and disposal zones. For example, DOE should identify down-hole logs, tests, and monitoring techniques that could lead to a better understanding of the potential development of a free gas phase (e.g., hydrogen from the rapid corrosion of steel components) and its implications for disposal system behavior. The goal for characterization should be obtaining relatively continuous down-hole profiles based on multiple measurements, instead of relying on, and interpolating between, a limited set of measurements. DOE also should consider using the characterization and field test boreholes to conduct cross-hole monitoring, to provide information on the characteristics of the rock volume surrounding the boreholes. Moreover, ongoing subsurface monitoring after the emplacement testing—to continue to test and evaluate starting assumptions—should be included in the drilling and test plan.*

- ***The Deep Borehole Field Test should include surface-based geophysical surveys to delineate subsurface structure and physical conditions prior to drilling (e.g., detailed gravity, magnetic, seismic, or electrical data).** These measurements could help in the design of the Deep Borehole Field Test drilling and test plan, and they could provide knowledge for using surface-based measurements to evaluate the subsurface characteristics of potential deep borehole sites prior to drilling.*

- ***DOE should explicitly analyze the potential safety benefits of using more robust waste forms and waste packages as part of assessing the feasibility of the deep borehole disposal concept and in developing the associated safety case.** The Board also recommends that the Deep Borehole Field Test be used to demonstrate emplacement of potential seals and to test the efficacy of seal materials in dealing with breakouts and evolving damage zones around the borehole when exposed to in situ thermal, hydrogeologic, geomechanical, microbiological, and chemical conditions. Geophysical techniques (e.g., acoustic sonic and ultrasonic tools) should be used to verify the seals between the casing and rock, where the casing remains in the borehole.*

- ***DOE should develop an operational safety strategy for the Deep Borehole Field Test that integrates conventional borehole operations and remote handling of highly radioactive materials.** This might include emphasizing the use of engineering controls* *(e.g., automated equipment to protect workers) over administrative controls (i.e., processes that rely on personnel actions and procedures). The Deep Borehole Field Test should simulate implementation of deep borehole disposal as if radioactive wastes were being emplaced, in order to test the features of an operational safety strategy that can be applied to a future borehole disposal site and to provide the basis for ensuring safe operations, limiting exposure of workers to hazards or release of radioactive material to the environment, and mitigating waste emplacement risks.*

- ***As part of its assessment of the feasibility of deep borehole disposal of radioactive waste, DOE should place a high priority on engaging regulators to define retrievability requirements in the context of deep borehole disposal of radioactive waste.*** *DOE should begin defining and clarifying the types of technical information that may be needed to address regulatory issues and then collect that information to the extent practicable as part of the Deep Borehole Field Test.*
- ***DOE should use the Deep Borehole Field Test to gain experience related to its siting approach.*** *DOE should begin to incorporate new standards of transparency and data access, and it should explore avenues to engage stakeholders.*
- ***The DOE Deep Borehole Field Test programs should have a chief scientist responsible for integrating the engineering activities (i.e., drilling the characterization and field test boreholes, emplacing and retrieving the simulated waste) and the site characterization activities.*** *The chief scientist should possess the scientific understanding required to ensure the technical integrity of information gathered in the Deep Borehole Field Test and its use for developing the safety case for deep borehole disposal of radioactive waste.*

On June 9, 2016, DOE formally responded to the Board's report on deep borehole disposal (DOE 2016b). That response is reproduced in Appendix F of this document.

Board Review of DOE's Activities Related to the Packaging and Transportation of Commercial HLW and SNF

Technical Workshop on the Impacts of Dry-Storage Canister Designs on the Future Handling, Storage, Transportation, and Geologic Disposal of Spent Nuclear Fuel

During November 18-19, 2013, the Board held a two-day workshop in Washington, DC, to explore the implications of the current nuclear power plant operator practice of loading SNF into very large dry-storage canisters.

Following discharge from nuclear reactors, SNF continues to generate heat, which decreases over time due to radioactive decay. Initially, nuclear power utilities stored SNF in water-filled pools at the nuclear power plant sites. Because the United States has no centralized storage facility or geologic repository for SNF, when these pools approach their licensed capacity, most utilities transfer the older, cooler, SNF assemblies to large dry-storage canister systems. By doing this, they create space in the pools to accommodate subsequent SNF discharges from continued reactor operations. To minimize the near-term economic and operational impacts of transferring SNF from pools to dry storage, nuclear utilities worked with storage system vendors to maximize the capacity of dry-storage systems. However, these storage systems were not designed for disposal, and many dry-storage canisters in use at utility sites today exceed the size, weight, and/or heat-load limits for repository concepts developed to date.

The design of the large dry-storage canister utilities used could have major implications for future SNF handling, storage, transportation, and disposal, as well as for a centralized interim storage facility's design and operation, should one be constructed. Potential impacts include the following:

Figure 6. Spent nuclear fuel storage casks at Idaho National Laboratory.

- Unless the large, dry-storage canisters used by nuclear utilities can be directly disposed of in a geologic repository, the SNF they contain will need to be repackaged into disposal containers before emplacement in a repository.
- Repackaging SNF currently in dry-storage canisters at nuclear utility sites would significantly impact the SNF manage ment system. For example, repackaging the SNF may be a lengthy process and could affect operational schedules at utility sites, at a consolidated storage facility, or at a repository, depending on where repackaging is performed. Repackaging the SNF also could involve extensive SNF assembly handling that could increase the potential for fuel damage and result in additional radiation exposure to workers; although, as for all other operations, worker radiation exposures would be managed in accordance with the appropriate regulatory limits. Repackaging also could generate a large volume of low-level waste that would require disposal.
- Because of the large size and high-heat output of the dry-storage canisters currently in use, their direct disposal might increase the degree of reliance on engineered barriers in the design of a repository. Direct disposal of the canisters also could increase the complexity of retrieval operations, if required, and may limit the geologic environments considered suitable for siting a repository for SNF disposal.

The workshop featured ten speakers, including DOE officials, DOE contractors and national laboratory specialists, NRC officials, and representatives from the international community, the electric utility industry, and nongovernmental organizations. The speakers examined the consequences of loading very large dry-storage canisters from a variety of perspectives, including cost, safety, security, and occupational exposure to nuclear power plant workers.

The Board described the workshop and summarized the issues the participants identified in a report (NWTRB 2014b).

Board Comments on the DOE Research and Development Program Related to Long-Term Dry Storage of High-Burnup Spent Nuclear Fuel

Between November 2013 and May 2014, Board members and staff attended seven meetings where experts discussed the potential consequences of extended dry-cask, high-burnup SNF storage. Based on the information presented at those meetings and the additional information Board members and staff gathered, the Board provided comments on the CDP and the broad R&D activities DOE-NE carried out (Ewing 2014e).

The Board views the CDP as a welcome first step in investigating key issues of potential degradation of high-burnup SNF and dry-storage systems during extended storage. The condition of dry-storage systems and the SNF they contain will need to be monitored over many decades in order to collect the necessary information to fully understand degradation mechanisms, and for calibrating codes developed to model changes in the condition of the SNF and storage systems over time. The CDP described in the test plan will provide important data to support all of these activities.

The Board, however, is concerned that according to the initial scope of the test plan, the information to be collected during the first ten-year storage period appears to be very limited. Most of the data will be derived from measurements made during examination—using nondestructive and/or destructive techniques—of fuel pellets, fuel cladding, fuel assembly hardware, and cask components (e.g., bolts and O-rings) at the beginning and at the end of the ten-year period. Originally, only cask temperature, inter-seal gas pressure, and external dose rates were to be monitored or measured during the storage period. Gas pressure measurements and gas sampling to determine the presence of fission gases, water vapor, oxygen, and hydrogen were planned to be conducted only during the two weeks after the cask is dewatered and the fuel is dried in preparation for moving the cask to the independent spent fuel storage installation (ISFSI) pad for the initial ten-year storage period. Thereafter, no measurements were initially planned that could be used to determine the rate of change of high-burnup SNF properties or the rate of degradation of storage system materials (if it occurs). Yet, the final test plan DOE published on February 27, 2014, states that "the EPRI team will continue to investigate and evaluate methods for performing gas sampling at the ISFSI during the longer-term storage period." If implemented, this sampling may be used to determine if any fuel rods fail during this period.

- *The Board supports efforts to sample and analyze gases that may be released from the fuel rods during the ten-year storage period.*

The Board notes that advanced sensors may provide an opportunity to monitor important parameters continuously. This would allow monitoring the condition of the SNF and the storage system during extended storage and subsequent transportation. The Board understands that consideration is now being given to installing universal ports in the cask lid that would permit additional internal instrumentation during periodic inspections planned over the full term of the project. The Board's view is that this will be a valuable and forward-looking extension to the planned cask lid modifications.

- *DOE should utilize or develop of instrumentation that can be installed in or attached to the canister when the SNF is loaded.*

- *If not already planned, DOE should consider basket modifications along with cask lid modifications to facilitate placing internal instrumentation. The Board understands that developing sensors and instrumentation will take time; however, we endorse implementing the planned passive cask-monitoring program at the earliest opportunity after due consideration is given to cask lid and basket modifications.*

Developing long-term in situ monitoring systems will require innovative approaches to overcome technical challenges, including the high-radiation environment inside the cask, the need to transmit data through cask walls if no universal lid ports or other penetrations are available, and the need for power sources that could support measurements for several years or decades. At the Board's January 31, 2014, meeting, DOE indicated that it is engaging other U.S. federal agencies, including the National Aeronautics and Space Administration and the Department of Defense, both of which have expertise in wired and wireless instrumentation, in an effort to benefit from their experiences in developing monitoring systems for harsh environments. Moreover, the National Nuclear Laboratory in the United Kingdom is researching energy scavenging techniques that may allow the decay heat or gamma radiation from SNF to be used to power monitoring instruments fitted into SNF storage systems.

- *The Board supports this interagency collaboration and encourages DOE also to look at work being undertaken in other countries that may also support these efforts.*

The CDP test plan states "that a large scale R&D project using various configurations of dry-storage cask systems and experiments would be beneficial." Tests that are initiated later in an expanded program could employ newly developed monitoring systems that can function in high-radiation fields. An alternative approach might be to open, over the next few years, several casks that contain fuels with a range of burnups and storage histories to examine the condition of the fuel and the storage system materials. Even though the information available on the initial status of the SNF in those casks may not be as extensive as that on the SNF in the CDP cask, important information could be gained from examining the condition of SNF stored in canisters that have been loaded previously.

- *The Board believes that using a statistically meaningful number of tests, as opposed to the single cask demonstration included in the CDP, would provide additional data and confidence in the results.*
- *The Board understands that DOE is now considering opening other SNF storage casks or canisters, possibly during the initial ten-year storage period of the CDP, and commends DOE for being prepared to undertake this additional research activity.*

A major issue that could affect the successful completion of the CDP is the current lack of a facility in the United States that can be used to unload the demonstration cask and to allow the fuel to be examined in a dry environment. Although the demonstration cask and additional systems that also may be included in the R&D program could be unloaded in existing wet pools, this would result in fuel and cladding temperature cycling, which could alter the results obtained from the SNF examination and make them less representative of SNF that remained in dry storage.

- *Consequently, the Board believes that high priority should be given to establishing a capability to open in a dry environment any of the dry-storage systems currently in use* *and to performing the full range of inspection and monitoring operations that may be required to meet the needs of the R&D program. We note that in its fiscal year 2015 budget, DOE's request for the Used Fuel Disposition Program includes funding to begin to develop this capability by adapting existing facilities at INL. The Board supports this initiative.*

The CDP test plan indicates that certification of a cask for transportation would occur after the cask has been certified for storage and loaded with high-burnup SNF. However, as the NRC's transportation requirements are separate from its storage requirements, this leaves open the possibility that the NRC might not certify the loaded TN-32 cask for transportation. If this were to occur, the SNF would have to be repackaged prior to shipment to the fuel examination facility, which would reduce the value of the results of the program.

- *The Board understands that there are competing priorities in the CDP and that, in the early years, the emphasis will be on activities such as modifying the cask lid and examining the fuel. However, we encourage DOE to include early certification of the cask for transportation in the schedule and list of key milestones.*[16]

The separate-effects test (SET) and small-scale test (SST) efforts, which were listed in the draft test plan, will be crucial to understanding key factors. They also would provide a wealth of validation data. According to the draft test plan, DOE's used nuclear fuel research, development, and demonstration strategies rely on these activities in implementing the large-scale prototype testing outlined in the test plan.

- *The Board considers it important to set priorities among the SETs and SSTs and to focus on early execution of the higher priority tests.*

Transporting Commercial Spent Nuclear Fuel

The Board held a public meeting in Golden, Colorado, on June 24, 2015, to review DOE activities on transporting commercial SNF. Among the areas covered were the transportability of SNF from shut-down as well as operating nuclear power plants; system-level analyses and their use in engaging interested and affected parties; chloride-induced stress corrosion cracking (CISCC) of SNF canisters under dry storage conditions; and the potential development of standardized transportation, aging, and disposal canisters (STAD). The Board's findings, conclusions, and recommendations were provided to DOE in a letter on August 31, 2015 (Ewing 2015a).

A DOE official described her unit's Nuclear Fuel Storage and Transportation Planning Project. She concluded that no significant technical issues stand in the way of transporting SNF from shut-down sites in the canisters or casks in which it is currently stored. Some technical issues would have to be resolved before some of the SNF held in canisters and casks licensed only for storage could receive the NRC approval it needs in order to be transported. In DOE's view, no technical challenges are likely to be encountered.

The Board is not as sanguine. The Board observes that many nuclear utilities are loading SNF into very large-capacity canisters. The weight of the combined canister and overpack

[16] In 2016, DOE replaced the acronym CDP with HDRP. It has defined that acronym variously as "High Burnup Spent Fuel Data Research Project" and "High Burn-up Confirmatory Data Research Project."

will likely exceed the capacity of standard transportation methods, and the load will have to be transported by a heavy-haul tractor-trailer or by rail on a specially designed rail car. The size and weight of these and similar loads may prevent transporting SNF, or limit the road or rail route options for transporting SNF, particularly from operating nuclear power plant sites. Further, the regulatory requirements for transporting certain commercial SNF canisters may be difficult to meet. DOE would be well served to address these technical challenges sooner rather than later.

- *DOE should work closely with nuclear utilities and the NRC to expeditiously define and resolve technical issues that may limit or prevent the transporting of SNF in current canisters and casks from nuclear power plant sites. As a result of such consultation, if repackaging the SNF is determined to be necessary, it is more likely that the site infrastructure to support repackaging would still be in place.*

DOE developed five major computer-based tools to assist in integration and analyses of SNF storage and transportation systems. Information about the detailed structure and planned use of some of the tools was not readily available. Nonetheless, these tools, especially START, may be quite useful in preventing loss of institutional knowledge as experienced personnel retire. Moreover, the tools can provide a vehicle for engaging communities on an issue that is typically highly contentious.[17]

- *DOE should expedite its efforts to finalize and publish documentation supporting its integration and planning tools associated with SNF transportation.*
- *DOE should consider producing a version of one of the five tools (START) not restricted for release, so that it can be demonstrated and provided to members of the public to increase their understanding of the constraints on routing options for SNF transportation. Such an effort should be initiated early in DOE's route selection process and be used to clearly explain all aspects of DOE's plans.*

The Board heard from a panel of experts drawn from national laboratories, EPRI, and NRC about the CISCC issue. Most dry-storage canisters are fabricated from austenitic stainless steel (304, 304L, 316, or 316LN stainless steel) and closed by welding on a stainless steel lid. Welding can create a heat-affected zone in the steel that is susceptible to various forms of corrosion, including CISCC, if the residual tensile stresses are sufficiently high and the local environment sufficiently aggressive. The locations of many dry-storage pads at nuclear power plant sites are especially vulnerable to chloride aerosol deposition and high humidity, which could combine to create conditions conducive to CISCC on the canister surfaces. One of the experts indicated that, whereas CISCC has not yet been found on any dry-storage canisters, it has been found in steel structures in similar atmospheric conditions. Given the possibility of high crack propagation rates from CISCC and extended dry-storage times, this issue requires attention.

Cracking of sensitized stainless steel under immersion conditions has been studied in detail, but this cracking phenomenon is much more complicated under atmospheric conditions where the susceptibility of the canisters to cracking will depend on several related factors. The local environment on the canister surface is critical, but it is variable and not

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[17] Jim Williams, representing the Western Interstate Energy Board, made this point in his presentation to the Board.

well understood under atmospheric conditions. Relevant parameters of the local environment include chloride concentration, temperature, and local humidity. The relationship of these parameters must be understood in order to develop meaningful models that can predict the initiation and progression of CISCC.

The state of stress at the welds and the resultant stress intensity at defects or corrosion pits are also critical for assessing the susceptibility to CISCC. It is not uncommon for residual stress to vary through the thickness of a component such that a tensile stress at the surface becomes a compressive stress at the interior, thus stifling crack growth and preventing penetration of the wall. One expert described ongoing experiments on a mock-up canister to assess the three-dimensional stress state. He indicated that some models predict the formation of short cracks perpendicular to the welds, which might impede further crack growth and not pose integrity concerns. The mock-up experiments will be very useful for validating such models.

The final important aspect of this issue is inspection. Another specialist stated that dry-storage systems in use were not designed to allow for inspection. The size and position of vents in the overpacks, as well as the high radiation field and temperature, make inspection extremely difficult. Fully automated inspection systems are not yet available; thus, inspection equipment is manipulated through the vents by hand. DOE is providing resources through the Nuclear Energy University Program and the Integrated Research Program at Pennsylvania State University and other schools to develop new systems to inspect the surfaces of canisters.

- *DOE should continue to work with EPRI and NRC; however, it should assume a greater leadership role in integrating R&D being performed by multiple organizations on CISCC of dry-storage canisters, particularly in (1) determining the environments on canister surfaces, (2) assessing the state of residual stress in the welded canisters, (3) determining the time interval until crack initiation under current storage conditions, (4) confirming crack growth rates, and (5) developing robust inspection tools and methods appropriate for the conditions and requirements of dry-storage systems.*
- *Regarding other research needs associated with commercial SNF, DOE should expand its leadership in identifying and communicating technical gaps, technical information needed to fill the gaps, and research being done on commercial SNF wet storage, drying, dry storage (on-site or centralized), transportation, and repackaging (if needed).*

An engineer from the Oak Ridge National Laboratory presented information about DOE's evaluation of the feasibility and potential benefits of using a STAD canister for commercial SNF. These benefits—which include common handling equipment, common transportation equipment, and common procedures and training programs—could improve operational efficiency and reduce overall program cost. If implemented, the STAD canister would be used to package commercial SNF taken directly from the spent fuel pools of commercial nuclear power plants. The STAD canisters would not be used for SNF that is currently stored in large dry-storage canisters because this would involve a significant effort to open the welded canisters, transfer the SNF, and dispose of the old canisters. Clearly, the potential benefit would significantly lessen as the time it takes to implement and deploy STAD canisters increased. DOE has not defined the STAD's purpose, scope, costs and benefits, and timing. Consequently, it has not made a decision to undertake development of a STAD. Making such a decision, the Board notes, could be challenging and have large uncertainties.

- *DOE should continue working closely with nuclear utilities to examine the implications of using a STAD canister, including the impacts of implementing a STAD canister at different times and at different repackaging locations (if repackaging is needed).*

On January 27, 2016, DOE formally responded to the Board's letter on commercial SNF transportation (DOE 2016a). That response is reproduced in Appendix F of this document.

Board Interactions with Congress

Testimony before and Correspondence with the House Subcommittee on Energy and Water Development, Committee on Appropriations

On April 11, 2013, Board Chairman Rodney Ewing, testified before the House Subcommittee on Energy and Water Development, Committee on Appropriations. He was invited to discuss, from the Board's technical prospective, three questions:

1. What do international and U.S. experiences tell us about consent-based siting?

2. What can we learn from Yucca Mountain, technically and otherwise?

3. What is the current thinking and consensus around preferable options for nuclear waste disposal and the siting of a geologic repository?

With respect to the first question, the chairman observed (Ewing 2013c),

> In general, most national programs for siting a deep-mined geologic repository for SNF and HLW are attempting to use some form of consent-based siting process—for very good reasons, but with varying degrees of success. As has been learned from siting efforts in this country, not having the consent of the affected units of government at the potential host site, including the state, community, and Native American Tribe(s) can create problems that delay or stop the process altogether. But using a consent-based process does not guarantee that a repository will be successfully sited, as was most recently demonstrated by the experience in the United Kingdom.

With respect to the second question, the chairman referred the subcommittee to the Board's report, *Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Wastes: Lessons from Yucca Mountain and Other Programs* (NWTRB 2011b). He summarized the report's technical conclusions:

1. A variety of geologies can be viable candidates for a repository, including intrusive or extrusive igneous rocks (e.g., granite and tuff), metamorphic (e.g., basement rocks of the Canadian Shield), and sedimentary rocks (e.g., salt and clay).

2. Expect surprises in any underground site investigation.

3. Engineered barriers can delay reliance on the waste-isolation capabilities of the natural system.

4. In general, in the presence of water, the higher the temperature, the more rapid will be the degradation (corrosion) of the waste package.

5. When compared with oxidizing environments, emplacement of high-activity waste in reducing environments has important advantages that enhance long-term isolation of the waste from the environment.

6. Natural analogs were invaluable for evaluating the Yucca Mountain site. Natural analogs should be identified and studied early as part of the site-characterization process.

In addition, the chairman noted that the report also made some comments about the institutional issues surrounding the development of a repository:

1. A deep-mined, geologic repository for the disposal of SNF and HLW is needed under all realistically foreseeable circumstances.
2. An implementing waste management organization that has continuity of funding, management, and personnel is very important.
3. Undue delay makes it difficult to implement a concept of waste management that depends on institutional stability.
4. Implementing a permanent repository could take decades.

With respect to the third question, the chairman pointed out that international consensus has formed, holding that disposal of HLW and SNF in deep-mined, geologic repositories is a workable and safe solution. He also stated that

> The Board's … analysis so far indicates that deep borehole disposal, if it proved to be physically feasible, might have some advantages for disposing of SNF and HLW that has little potential for reuse. However, vitrified waste as it currently exists—in metal canisters filled with glass—may be too large for the boreholes envisioned for deep borehole disposal. Also, commercially generated SNF and DOE-managed SNF is stored in canisters with a wide-range of sizes and shapes, so repackaging into smaller canisters also would be required for that waste. There are other daunting challenges associated with deep borehole disposal related to developing new drilling technologies, the emplacement and effective sealing of waste packages at great depth, and the need to address the potential retrieval of the emplaced waste.

He concluded, however, that "because of the present uncertainties associated with deep-borehole technologies, the Board recommends that deep borehole research and development not distract the U.S. program from vigorously pursuing the siting and characterization of a deep-mined geologic repository."

With respect to options for siting a repository, the chairman made the following points:

1. There must be a set of technical criteria by which sites are evaluated.
2. There should be a clear statement of how all affected units of government (e.g., local community, Native American tribe, and state) will be engaged in the consent-based process.
3. There should be a clearly understood process by which the affected units of government can opt out of the siting process
4. There should be a clear understanding of the time after which the affected units of government can no longer withdraw their consent.

After Chairman Ewing's appearance before the subcommittee, the Board carried out a study visit to Sweden and France to learn more about how the waste-management programs in both countries were organized and how difficult technical challenges were addressed. The Board followed up the chairman's testimony to the House Subcommittee on Energy and Water Development with a letter to Subcommittee Chairman Rodney Frelinghuysen; it detailed the observations, insights, and conclusions developed during that study visit (Ewing 2013a).[18] The contents of this letter are described below. The letter is reproduced in Appendix D.

Comments on the Senate Committee on Energy and Natural Resources' Discussion Draft of Comprehensive Nuclear Waste Legislation

On April 25, 2013, the Senate Committee on Energy and Natural Resources released a discussion draft of comprehensive nuclear waste legislation. On June 7, 2013, the Board provided the committee with its comments on the draft (NWTRB 2013a). The comments relied on two Board reports, *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel* (NWTRB 2009) and *Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries* (NWTRB 2011a.) The comments focused on provisions of the proposed legislation that would affect or would be affected by technical issues, including consent-based siting processes, site characterization, safety case and regulatory standards, implementing organizations, and transportation of defense waste. It also responded to two questions about SNF storage facilities siting.

International Activities

Board Study Visit to Sweden and France

In June 2013, a Board delegation took part in a study visit to Sweden and France. In Sweden, the Board met with officials from the Swedish regulator, and the Board's sister agency, the Swedish National Council for Nuclear Waste. It met with representatives from the two municipalities that hosted waste-management facilities, Oskarshamn and Ősthammar. The Board received detailed presentations from the implementer, the

[18] Copies of the letter were also sent to the chairman and ranking minority member of the Senate Energy and Natural Resources Committee and to the chairman and ranking minority member of the Senate Committee on Public Works, Subcommittee on Clean Air and Nuclear Safety.

Swedish Nuclear Fuel and Waste Management Company (SKB), and visited its underground research laboratory, spent fuel storage facility, and low- and intermediate-waste disposal repository. In France, the Board visited AREVA's La Hague reprocessing facility and intermodal transfer terminal, the Alternative Energies and Atomic Energy Commission's Marcoule Research Center, and the underground research laboratory operated by the French implementer, the National Radioactive Waste Management Agency (ANDRA).

As discussed above, one of the key recommendations of the Blue Ribbon Commission on America's Nuclear Future was that a new implementing organization should replace DOE. For that reason, one of the main foci of this study visit was to understand how the two implementers, SKB and ANDRA, addressed challenging technical issues. The Board's views on this question were sent to the House Subcommittee on Energy and Water Development, Committee on Appropriations (Ewing 2013a).

From its interactions with the two implementers, the Board came to appreciate what "ingredients" might be necessary (although probably not sufficient) to carry out a technically sound repository development process. Three appear worthy of note: (1) steady availability of resources, (2) adaptability, and (3) attention to the details of deployment.

One consequence of operating within a relatively stable political environment is that there is broadly based support for work to address long-term safety questions. This continuity is crucial because establishing the case for a repository is a decades-long and sometimes tedious process. For example, the Swedish safety case relies on the integrity of a bentonite barrier that surrounds the waste packages, minimizing water flow past them and absorbing radionuclides that might be released. The French safety case relies on the slow movement of water through argillite (clay-rich rock) formations. Demonstrating the capabilities of these barriers requires investigations that have to be conducted over substantial periods of time. Experience in Sweden and France indicates that long-term, multiyear, ensured budgets provided a number of benefits, including more efficient planning and implementation of an integrated research program and the retention of key personnel.

A stepwise and adaptive repository development process is premised on the likelihood that new technical information or shifts in policy might demand midcourse modifications. Both implementers have demonstrated a capacity—albeit sometimes imperfectly—to make adjustments in a technically credible and publicly transparent manner.

Another element of the Swedish safety case is the assertion that waste canisters fabricated from elemental copper will not corrode in the anoxic groundwater to which they will be exposed. That proposition appeared for many years to be supported by fundamental principles of thermodynamics. Experiments conducted at the Swedish Royal Institute of Technology (KTH), however, called that claim into question. The regulatory authorities expressed considerable interest in this new information. SKB's response was twofold. It supported a pair of independent investigations to see if the KTH results could be replicated and sponsored the formal "reference group" of interested and affected parties to monitor the progress of those studies. SKB also performed additional safety assessments to determine the consequences for public health if the KTH findings were substantiated.

The French implementer also faced challenges to its approach. A public debate held in 2005 revealed a strong preference for a disposal concept that permits reversibility for perhaps as many as one hundred years. That public demand was incorporated into legislation in 2006. Since then, ANDRA has been working on alternative repository designs that would satisfy the law's requirements. These were the subject of technical conferences and were opened up to international peer review. ANDRA will need to choose one design when it submits a license application to the regulatory authorities.

SKB and ANDRA understand better than OCRWM did that their responsibilities extend beyond articulating a safety case and supporting it before the public and the regulators. Both SKB and ANDRA are looking ahead to determine what it will take to operate a deep-mined, geologic repository in a manner that will not endanger the trust that the organizations have built up over the years. For that reason, both implementers constructed underground research laboratories in rock formations and at depths virtually identical to those where a repository might be developed. They also concluded that it is essential to develop full-scale prototypes of critical systems before a license application is submitted and to test the performance of those systems in situ. Neither SKB nor ANDRA is prepared to claim that the technologies required could be taken off the shelf or would somehow become available at a later stage.

One of the greatest challenges that all implementers will face is the emplacement of waste packages and engineered barrier systems (EBS) within the host rock. This operation, which typically will have to be performed in a high-radiation, low-visibility environment, will need to be executed remotely. Should the EBS be misaligned or incorrectly emplaced, the long-term safety of the repository could be degraded and perhaps jeopardized.

The Swedish disposal concept specifies that, before a waste package is lowered into the host rock, highly compacted bentonite blocks and rings have to be placed into the vertical disposition holes. The tolerances are extraordinarily tight. To determine whether the emplacement requirements could be met, SKB constructed prototype machines for installing the bentonite and for depositing the waste package. These systems were repeatedly tested (in a nonradiological but underground environment) using fully automated navigation and positioning systems.

In the French disposal concept, the EBS relies heavily on the waste package. However, because of the reversibility requirement enacted by Parliament, ANDRA has had to determine not only how to emplace the packages inside horizontal holes bored in the repository tunnels' walls but also how to extract the packages if so required. Several full-scale prototypes were developed, and preliminary tests were conducted. Although final design requirements have not been set, ANDRA seems to feel confident that it can develop the technologies needed to implement the reversible emplacement of waste.

Board Study Visit to the People's Republic of China

In May, 2014, a small Board delegation visited the People's Republic of China to learn more about its waste-management program. The delegation met with officials from a number of organizations, including the implementer, the Beijing Research Institute for Uranium Geology (BRIUG), the China Atomic Energy Authority, the China National Nuclear Corporation (CNNC), the Nuclear Power Engineering Company (CNPE), the China Institute for Atomic Energy (CIAE), and the regulator, the Chinese National Nuclear Safety Administration. BRIUG and the Board organized a workshop where scientists and engineers from both countries made presentations on important technical issues. Finally, the Board delegation was invited to visit the proposed underground research laboratory/repository site at Beishan in Gansu Province.

The dominant "nongovernmental" organization that the Board delegation engaged was the state-owned CNNC, which controls directly or indirectly the entire front end of the nuclear fuel cycle, all the nuclear power plants, and the small number of branches working on radioactive waste management.

Within the CNNC, three organizations play important roles in developing a repository. BRIUG has been the lead research institute for more than thirty years. Up until recently, it conducted all the technical studies on repository siting. The CIAE conducts research on waste forms, almost exclusively vitrified glass. The Board delegation visited laboratories studying the behavior of glass under various environmental conditions and visited the prototype fast-reactor control room. Finally, the CNPE is involved in designing nuclear power plants, expects to be the lead organization for constructing any future underground research laboratory, and recently became a strong advocate for deep borehole disposal.

Overall, the visit was a productive and valuable one. The Board delegation was generally impressed with the progress that China's program is making. The Chinese scientific and technical experts were interested in hearing suggestions from the delegation about what studies might be undertaken in the future. Both sides recognized that the institutional structure for the Chinese waste-management program is still immature, as is the regulatory framework.

Board Participation in the Activities of the Advisory Bodies to Government

In 2004, the Nuclear Energy Agency, a unit of the Organization for Economic Cooperation and Development, established an informal group called the Advisory Bodies to Government (ABG). Its purpose is to bring together the chairs of entities, such as the Board, that provide advice to policymaking levels of the national government. ABG meetings are held roughly every eighteen months.

The composition of the ABG has varied over the years, but during the period covered by this report, its members included:

- Commission on National Evaluation (France)

- Nuclear Waste Management Commission (Germany)
- National Council for Nuclear Waste (Sweden)
- Nuclear Safety Commission (Switzerland)
- Committee on Radioactive Waste Management (United Kingdom)
- Nuclear Waste Technical Review Board (United States)

The Board participated in an ABG meeting in London in October 2013 and another one in Berlin in May 2015. At each meeting, the chairs provided an update on each country's radioactive waste-management activities. In addition, the chairs discussed issues common to each organization.

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Acronyms

ASLB	Atomic Safety and Licensing Board
Board	U.S. Nuclear Waste Technical Review Board
BRC	Blue Ribbon Commission on America's Nuclear Future
CDP	High Burnup Dry Storage Cask Research and Development Project
CISCC	chloride-induced stress corrosion cracking
DOE	U.S. Department of Energy
DOE-EM	Department of Energy–Office of Environmental Management
DOE-NE	Department of Energy–Office of Nuclear Energy
EPRI	Electric Power Research Institute
HDRP	High Burnup Spent Fuel Data Research Project OR High Burnup Confirmatory Data Research Project
HLW	high-level radioactive waste
INL	Idaho National Laboratory
LANL	Los Alamos National Laboratory
LM	Office of Legacy Management
LSNdc	Licensing Support Network Document Collection
NARA	National Archives and Records Administration
NRC	Nuclear Regulatory Commission
NSNFP	National Spent Nuclear Fuel Program

NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
OCRWM	Office of Civilian Radioactive Waste Management
R&D	research and development
RIS	Records Information System
SER	Safety Evaluation Report
SET	separate-effects test
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SST	small-scale test
STAD	standardized transportation, aging, and disposal canisters
WIPP	Waste Isolation Pilot Plant
WVDP	West Valley Demonstration Project
YMP	Yucca Mountain Project
YMRIS	Yucca Mountain Record Information System

Glossary

Argillite A compact rock derived from claystone, siltstone, or shale that is more indurated than its constituent source rock but less laminated and fissile than shale and lacking the cleavage of slate.

Anoxic groundwater Subsurface water that has been depleted of dissolved oxygen.

Backfill The material used to refill excavated parts of a repository during and after waste emplacement.

Bentonite A soft, light-colored clay formed by chemical alteration of volcanic ash. Bentonite has been proposed for backfill and buffer material in many repositories.

Crystalline basement rock A generic term for igneous rocks and metamorphic rocks (e.g., granite, gneiss, and basalt) that are below sedimentary deposits.

Deep borehole disposal Waste disposal in a cylindrical excavation drilled into deep, basement rock.

Deep-mined, geologic disposal A facility for disposal of radioactive waste located underground (usually several hundred meters or more below the surface) in a geological formation intended to provide long-term isolation of radionuclides for the biosphere.

Engineered barrier The designed or engineered components of a repository, including waste packages and other features.

Finite element A method for studying continuous physical systems in which the system is broken into discrete elements. Each element is studied separately and then the results are reconnected.

Hydrogeologic environment Subsurface waters, their movement, and effects in basement rock.

Isochoric deformation Changing the shape of something while the volume remains constant.

Lithostatic pressure Pressure due to the weight of overlying rock, soil, and water.

Multicanister overpack A stainless steel container for interim storage of spent nuclear fuel. The multicanister overpack is a cylindrical tube with a plate welded at the bottom and a shield plug at the top; five or six baskets loaded with intact fuel rods or fuel pieces are stacked inside the multicanister overpack.

Multiphysics Simulations that involve multiple physical models or multiple simultaneous physical phenomena.

Salt creep Situation in which salt in groundwater flows plastically, causing catastrophic pressure against repository components.

Source term Types and amounts of radioactive or hazardous material released to the environment.

Triaxial strength test A test in which a cylindrical sample of rock encased in an impervious membrane is subjected to confining pressure to failure.

Vitrification Mixing processed radioactive waste with glass fragments in a furnace to stabilize the waste into a form that will neither react nor degrade for extended periods of time.

Zircaloy The trademark name for a family of alloys of zirconium and small amounts of tin, iron, chromium, and nickel.

Appendices

A. Board Members during the Reporting Period

B. Board Strategic Plan 2014–2018

C. Board Publications

D. Congressional Testimony and Correspondence

E. Board Meetings: January 2013–December 31, 2015

F. Correspondence with the U.S. Department of Energy: January 1, 2013–December 31, 2015

Appendix A

Board Members during the Reporting Period

Rodney C. Ewing, Ph.D., Chairman

Dr. Rodney C. Ewing was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on July 28, 2011, and was designated by the president to serve as chairman of the Board on September 25, 2012. Dr. Ewing was reappointed as chairman and member of the Board by the president on July 1, 2014.

Dr. Ewing is the Frank Stanton Professor in Nuclear Security in the Center for International Security and Cooperation, and a professor of geological sciences in the School of Earth, Energy and Environmental Sciences at Stanford University. He is also the Edward H. Kraus Distinguished University Professor Emeritus at the University of Michigan and Regents' Professor Emeritus at the University of New Mexico.

Dr. Ewing is a fellow of the Geological Society of America, the Mineralogical Society of America, the American Geophysical Union, the Geochemical Society, the American Ceramic Society, the American Association for the Advancement of Science, and the Materials Research Society. He was a guest scientist at numerous institutions, including the Centre d'Études Nucléaires, Commissariat à l'Énergie Atomique et aux Énergies Alternatives in Fontenay-Aux-Roses, France; Hahn-Meitner Institut in Berlin; and the University of Tokyo.

Among Dr. Ewing's numerous awards and honors are the Royal Society of Canada, Foreign Fellow; an Honorary Doctor of Université Pierre et Marie Curie; the Dana Medal of the Mineralogical Society of America; the Lomonosov Great Gold Medal of the Russian Academy of Sciences; the Roebling Medal of the Mineralogical Society of America; and the Association of Earth Science Editors Award for Outstanding Editorial or Publishing Contributions.

Dr. Ewing has written extensively on issues related to nuclear waste management and is coeditor of *Radioactive Waste Forms for the Future* (1988) and *Uncertainty Underground—Yucca Mountain and the Nation's High-Level Nuclear Waste* (2006). He has published more than seven hundred scientific papers in journals and proceedings volumes.

Dr. Ewing received a Ph.D. from Stanford University in 1974 and an M.S. from Stanford in 1972. He received a B.S. in geology from Texas Christian University.

Dr. Ewing lives in Menlo Park, California.

Jean M. Bahr, Ph.D.

Dr. Jean M. Bahr was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012.

Dr. Bahr is a professor in the Department of Geoscience at the University of Wisconsin (UW)-Madison, where she has been on the faculty since 1987. She also is a faculty member of the UW-Madison Geological Engineering Program and a faculty affiliate of the Nelson Institute for Environmental Studies. She chaired the Department of Geoscience (formerly Geology and Geophysics) from 2005 to 2008, and the Nelson Institute's Water Resources Management Graduate Program from 1995 to 1999. Dr. Bahr's research explores physical, geochemical, and biogeochemical controls on the movement of water and associated solutes in subsurface geologic systems.

Dr. Bahr served on many advisory committees through the National Research Council of the National Academies and was a member of the Board on Radioactive Waste Management from 1992 to 1997. She chaired the Committee on Restoration of the Greater Everglades Ecosystem, and from 2004 to 2006 she was a member of the Committee on Research Priorities in Earth Science and Public Health. In addition to her service for the National Academies, Dr. Bahr has been a member of proposal review panels for the National Science Foundation, the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the international Ocean Drilling Program. She served terms on the editorial boards of *Water Resources Research*, *Ground Water*, and *Hydrogeology Journal*.

Dr. Bahr was elected to Sigma Xi in 1984, named a fellow of the Geological Society of America (GSA) in 1996, and received the GSA Hydrogeology Division's Distinguished Service Award in 2006. She was the 2003 GSA Birdsall-Dreiss Distinguished Lecturer and was elected president of GSA for 2009–2010. She will serve as president of the American Geosciences Institute in 2017. She was named a lifetime National Associate of the National Academies in 2002 and is the 2012 recipient of the Association for Women Geoscientists' Outstanding Educator Award.

Dr. Bahr received a B.A. in geology and geophysics from Yale University in 1976 and an M.S. and a Ph.D. in 1985 and 1987, respectively, in applied earth sciences (hydrogeology) from Stanford University.

Dr. Bahr resides in Madison, Wisconsin.

Steven M. Becker, Ph.D.

Dr. Steven M. Becker was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012.

Dr. Becker is a professor of community and environmental health in the College of Health Sciences at Old Dominion University in Norfolk, Virginia. He is a leading expert in emergency planning, public health preparedness and response, and crisis and emergency risk communication for chemical, biological, radiological, and nuclear issues, and other emerging health challenges. Dr. Becker also has extensive on-the-ground experience at the sites of major accidents, disasters, and emergencies around the world. In 2011, he was a member of a three-person assistance team invited to Japan in response to the earthquake-tsunami and accident at the Fukushima Daiichi nuclear plant.

In 2005, Dr. Becker was elected by his scientific peers to serve on the National Council on Radiation Protection and Measurements. For the past 15 years, he also has been an invited faculty member for the Harvard School of Public Health professional training course on radiological emergency planning. His research on emergency preparedness and response, emergency messaging, and risk communication was recognized with awards from such scientific organizations as the Health Physics Society and Oak Ridge Associated Universities.

Dr. Becker holds a B.A. from George Washington University, an M.A. from Columbia University, and a Ph.D. from Bryn Mawr College. He also was a Kreitman Scholar and postdoctoral fellow at Ben-Gurion University of the Negev in Israel and a visiting fellow at the Japan Emergency Medicine Foundation and National Hospital Tokyo Disaster Medical Center.

Susan L. Brantley, Ph.D.

Dr. Susan L. Brantley was appointed to the U.S. Nuclear Waste Technical Review Board on September 25, 2012, by President Barack Obama.

Dr. Brantley is a Distinguished Professor of Geosciences in the College of Earth and Mineral Sciences at Pennsylvania State University, where she is also the director of the Earth and Environmental Systems Institute. She has been a faculty member at the university since 1986. As a geochemist, Dr. Brantley concentrated on the chemistry of natural waters, both at the surface of the earth and deeper in the crust. Much of her research focuses on understanding what controls the chemistry of natural water and how water interacts with the rocks through which it flows. Through field and laboratory work, and theoretical modeling of observations, Dr. Brantley and her research group investigate chemical, biological, and physical processes associated with aqueous fluids circulation in shallow hydrogeologic settings. Of particular interest are questions concerning measuring and predicting the rates of natural processes, with and without microorganisms. Her recent work has focused on the processes that transform rock into soil and the relationship between shale gas development and water quality. Dr. Brantley has published more than two hundred refereed journal articles and fifteen book chapters.

Professor Brantley is a fellow of the American Geophysical Union, the Geological Society of America, the Geochemical Society, the European Association of Geochemistry, and the International Association for GeoChemistry. She was president of the Geochemical Society from 2006 to 2008. She has served on several National Research Council committees.

In 2011, Professor Brantley received the Arthur L. Day Medal from the Geological Society of America as well as an honorary doctorate from the Paul Sabatier University (Toulouse III) in France. In 2012, she received the Presidential Award from the Soil Science Society of America, and she also was elected to membership in the U.S. National Academy of Sciences. In 2016, she received the Wollaston Medal from the Geological Society of London.

Dr. Brantley received an A.B. in chemistry in 1980 and an M.A. and a Ph.D. in geological and geophysical sciences in 1983 and 1987, respectively, from Princeton University.

Dr. Brantley lives in State College, Pennsylvania.

Sue B. Clark, Ph.D.*

Dr. Sue B. Clark was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on July 28, 2011. Dr. Clark was reappointed to the Board by the president on July 1, 2014.

Dr. Clark is Regents Professor of Chemistry at Washington State University in Pullman, Washington, where she has taught and conducted research in actinide environmental chemistry and radioanalytical chemistry since 1996. From 1992 to 1996, she was a research ecologist at the University of Georgia's Savannah River Ecology Laboratory. From 1991 to 1996, she was an adjunct assistant professor in the Environmental Systems Engineering Department at Clemson University, and from 1989 to 1992, she was a senior scientist in the Interim Waste Technology Division at the Westinghouse Savannah River Laboratory.

Dr. Clark has served on numerous national advisory committees. From 2009 to 2011, she was a member of the Board of Directors of the U.S. Council for Chemical Research. From 2005 to 2009, she served on the Nuclear and Radiation Studies Board of the National Research Council. From 2004 to 2005, she served on the Board on Radioactive Waste Management of the National Research Council and various study committees for that Board. From 2003 to 2011, she was a member of the Basic Energy Sciences Advisory Committee of the Office of Science, U.S. Department of Energy.

Dr. Clark's awards and achievements include being a fellow of the American Chemical Society, selected in 2010. In 2008, she was Fink Distinguished Lecturer, Georgia Institute of Technology, Department of Chemistry. From 2002 to 2008, she was Westinghouse Distinguished Professor of Materials Science and Engineering at Washington State University.

Professor Clark has published over one hundred peer-reviewed papers in environmental chemistry of plutonium and other actinides, chemistry of high-level radioactive waste systems, and actinide radioanalytical chemistry. She is currently serving as an editor for the journal *Radiochimica Acta*. Dr. Clark earned a Ph.D. and an M.S. in inorganic/radiochemistry from The Florida State University. She earned a B.S. in chemistry from Lander College in Greenwood, South Carolina.

Dr. Clark lives in Pullman, Washington.

* The text included here reflects Dr. Clark's biographical information when she served on the Board. Parts of the bio are no longer current.

Allen G. Croff

Allen G. Croff was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on February 23, 2015.

Mr. Croff is an adjunct professor in the Civil and Environmental Department at Vanderbilt University in Nashville, Tennessee. His areas of expertise include radioactive waste generation, classification, processing, storage, transportation, and disposal; nuclear fuel cycle systems and economic analysis and regulation; modeling radionuclide production and depletion; radionuclide separation and transmutation; waste repository site identification, regulation, and assessment; and clean-up of U.S. Department of Energy (DOE) legacy sites.

Mr. Croff worked at Oak Ridge National Laboratory for almost thirty years. He is a member of the National Council on Radiation Protection and Measurements (NCRP) and has served on ten committees of the National Academy of Sciences and on its Nuclear and Radiation Studies Board. He was also a member of DOE's Nuclear Energy Research Advisory Committee and served on the staff of the Blue Ribbon Commission on America's Nuclear Future. He was Chairman of the Nuclear Development Committee of the Nuclear Energy Agency for ten years and Vice-Chairman of the Nuclear Regulatory Commission's Advisory Committee on Radioactive Waste Management for four years.

Mr. Croff's writings and publications include contributions to five books, ten National Academy of Sciences reports, an NCRP report, and numerous national laboratory reports and peer-reviewed conference papers.

Mr. Croff received a B.S. (1971) in chemical engineering from the Michigan State University, a Nuclear Engineer Degree (1974) from the Massachusetts Institute of Technology, and an M.B.A. (1981) from the University of Tennessee.

Mr. Croff resides in Saint Augustine, Florida.

Efi Foufoula-Georgiou, Ph.D.

Dr. Efi Foufoula-Georgiou was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012.

Dr. Foufoula-Georgiou is a distinguished professor in the Department of Civil and Environmental Engineering at the University of California, Irvine. She served as director of the National Science Foundation (NSF) Science and Technology Center "National Center for Earth-Surface Dynamics" and director of the St. Anthony Falls Laboratory at the University of Minnesota. Her areas of research are hydrology and geomorphology, with a special interest in scaling theories, multiscale dynamics, and space-time modeling of precipitation and landforms.

Dr. Foufoula-Georgiou served on many national and international advisory boards, including the Water Science and Technology Board of the National Academies, the Advisory Council of the Geosciences Directorate of NSF, and the Earth Sciences Subcommittee of the Science Advisory Council of the National Aeronautics and Space Administration. She has also been a member of several National Research Council committees; the most recent one produced the report *Challenges and Opportunities in the Hydrologic Sciences*. She chaired the Board of Directors of the Consortium of Universities for the Advancement of Hydrologic Sciences and served as an elected trustee of the University Corporation for Atmospheric Research. Dr. Foufoula-Georgiou published over 130 journal-refereed papers and received the John Dalton Medal of the European Geophysical Union, the Hydrologic Sciences Award of the American Geophysical Union (AGU), and the Robert E. Horton Lecture award of the American Meteorological Society (AMS). She is a fellow of AGU and AMS and is an elected member of the European Academy of Sciences. In 2012, she was elected president of the Hydrology Section of AGU.

Dr. Foufoula-Georgiou received a diploma in civil engineering (1979) from the National Technical University of Athens, Greece, and an M.S. and a Ph.D. (1985) in environmental engineering from the University of Florida.

Dr. Foufoula-Georgiou resides in Irvine, California.

Gerald S. Frankel, Sc.D.**

Dr. Gerald S. Frankel was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012.

Dr. Frankel is the DNV chair, professor of materials science and engineering, and director of the Fontana Corrosion Center at The Ohio State University (OSU). Before joining OSU, he was a postdoctoral researcher at the Swiss Federal Technical Institute in Zurich and a research staff member at the IBM Watson Research Center in Yorktown Heights, New York. His primary research interests are in the passivation and localized corrosion of metals and alloys, corrosion inhibition, and protective coatings.

Dr. Frankel is on the editorial boards of the journals *Corrosion*, *Corrosion Reviews*, *Materials and Corrosion*, and *The Journal of the Electrochemical Society*. He is past chairman of both the Corrosion Division of The Electrochemical Society and the Research Committee of NACE International. Dr. Frankel is a fellow of NACE International, The Electrochemical Society, and ASM International. He received the W.R. Whitney Award from NACE International in 2015, the U.R. Evans Award from the Institute of Corrosion in 2011, the OSU Distinguished Scholar Award in 2010, the 2010 ECS Corrosion Division H.H. Uhlig Award, the Alexander von Humboldt Foundation Research Award for Senior U.S. Scientists in 2004, the 2007 T.P. Hoar Prize from the U.K. Institute of Corrosion, the 2000 H.H. Uhlig Award from NACE, and the Harrison Faculty Award from the OSU College of Engineering in 2000. He was on sabbatical at the Max Planck Institute for Iron Research in Dusseldorf in 2005, a visiting professor at the University of Paris in 2008, and a visiting professor at Monash University in Melbourne, Australia, in 2012.

Dr. Frankel earned an Sc.B. degree in materials science and engineering from Brown University in 1978 and an Sc.D. degree in materials science and engineering from The Massachusetts Institute of Technology in 1985.

Dr. Frankel resides in Bexley, Ohio.

** Dr. Frankel resigned from the Board effective August 15, 2016, to focus on his work at The Ohio State University.

Linda K. Nozick, Ph.D.

Dr. Linda Nozick was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on July 28, 2011. Dr. Nozick was reappointed to the Board by the president on July 1, 2014.

Dr. Nozick is a professor and the director of civil and environmental engineering at Cornell University. She has also served as the director of the College Program in Systems Engineering, a program she cofounded. She has been on the Cornell faculty since 1992 and has been a full professor since 2003. From 1998 to 1999, Dr. Nozick was visiting associate professor in the Operations Research Department at the U.S. Naval Postgraduate School in Monterey, California. In 1998, she was visiting professor in the Operations Research Department at General Motors Research & Development in Warren, Michigan. She played a leading role in developing optimization models for planning and policy to support the National Security Enterprise and Homeland Security.

Dr. Nozick served on two National Academy committees to advise the U.S. Department of Energy on renewal of their infrastructure. She authored more than sixty peer-reviewed publications, many of which focused on transportation, moving hazardous materials, and modeling critical infrastructure systems. She was an associate editor for *Naval Research Logistics* and on the editorial board of *Transportation Research Part A*.

She has received numerous awards, including a CAREER award from the National Science Foundation and a Presidential Early Career Award for Scientists and Engineers from President Bill Clinton for "the development of innovative solutions to problems associated with the transportation of hazardous waste." Dr. Nozick also received several recognition awards from Sandia National Laboratories and the National Nuclear Security Administration for developing modeling tools for nuclear stockpile analysis, transporting hazardous/sensitive materials, enterprise planning, and budget analysis.

Dr. Nozick received a Ph.D. and an M.S.E. in systems engineering from The University of Pennsylvania and a B.S. in systems analysis and engineering from The George Washington University.

Dr. Nozick lives in Ithaca, New York.

Kenneth Lee Peddicord, Ph.D., P.E.

Dr. Kenneth L. Peddicord was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012. Dr. Peddicord was reappointed to the Board by the president on July 1, 2014.

Dr. Peddicord is the director of the Nuclear Power Institute (NPI) and a professor of nuclear engineering at Texas A&M University, where he has been a faculty member since 1983. From 1972 to 1975, he was employed as a research nuclear engineer at the Eidgenössisches Institut für Reaktorforschung (the Swiss Federal Institute for Reactor Research), now the Paul Scherrer Institut, in Würenlingen, Switzerland. From 1975 to 1981, he was an assistant professor and an associate professor of nuclear engineering at Oregon State University. From 1981 to 1982, he was a visiting scientist at the EURATOM Joint Research Centre in Ispra, Italy.

At Texas A&M University, Dr. Peddicord has served as head of the Department of Nuclear Engineering, associate dean and interim dean of the College of Engineering, and associate vice chancellor and vice chancellor of The Texas A&M University System for Research and Federal Relations. Since 2007, he has been the Director of NPI, a joint institute of the Texas Engineering Experiment Station and Texas A&M University. NPI is a partnership involving universities, community colleges, industry, high schools and junior highs, teachers, students, elected and civic leaders, and government agencies. The focus is to inform, attract, and prepare students for the nuclear industry.

Dr. Peddicord has published more than two hundred articles, papers, and reports. His technical interests include nuclear engineering education, human resources and nuclear workforce development, and advanced nuclear fuels. He is a licensed professional engineer in the state of Texas.

Dr. Peddicord received a B.S. degree in mechanical engineering from the University of Notre Dame in 1965, and an M.S. in 1967 and a Ph.D. in 1972 in nuclear engineering from the University of Illinois at Urbana-Champaign.

Dr. Peddicord resides in College Station, Texas.

Paul J. Turinsky, Ph.D.

Dr. Paul J. Turinsky was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012. Dr. Turinsky was reappointed to the Board by the president on July 1, 2014.

Dr. Turinsky is a professor of nuclear engineering at North Carolina State University in Raleigh, North Carolina.

Dr. Turinsky's areas of expertise are computational reactor physics in support of mathematical optimization of fuel management and nuclear fuel-cycle multiobjective decisions, uncertainty quantification and data assimilation in support of optimum experimental design applied to nuclear power plant safety and fuel-cycle assessments, and adaptive model refinement applied to nuclear power plant transient simulation.

Dr. Turinsky's writings and publications include contributions to three books and numerous peer-reviewed technical publications. He is the recipient of the American Society for Engineering Education Glenn Murphy Award, the Edison Electric Institute Power Engineering Educator Award, the U.S. Department of Energy (DOE) E.O. Lawrence Award in Atomic Energy, and the American Nuclear Society (ANS) Eugene P. Wigner Reactor Physics Award and Arthur Holly Compton Award.

Dr. Turinsky was on the faculty of Rensselear Polytechnic Institute and held engineering and management positions at Westinghouse Electric Corporation. From 2010 to 2016, he served as the chief scientist for DOE's Innovation Hub for Modeling and Simulation of Nuclear Reactors. He also served on the Commissariat à l'énergie atomique, Scientific Committee of the Nuclear Energy Division, the Duke Power Company Nuclear Safety Review Board, the DOE Fuel Cycle R&D External Review Committee, and the Board of Managers of Battelle Energy Alliance.

Dr. Turinsky is a fellow of ANS; he is a member of the Society for Industrial and Applied Mathematics, the American Society for Engineering Education, and the American Association for the Advancement of Science.

Dr. Turinsky received a B.S. (1966) in chemical engineering from the University of Rhode Island, an M.S.E. (1967) and a Ph.D. (1970) in nuclear engineering from the University of Michigan, and an M.B.A. (1979) from the University of Pittsburgh.

Dr. Turinsky resides in Raleigh, North Carolina.

Mary Lou Zoback, Ph.D.

Dr. Mary Lou Zoback was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012.

Dr. Zoback is a seismologist and a consulting professor in the Geophysics Department at Stanford University. From 2006 to 2011, she was vice president for earthquake risk applications with Risk Management Solutions, a private catastrophe-modeling firm serving the insurance industry. In that role, she utilized the company's commercial risk models to explore the societal role of earthquake insurance and to quantify the costs and benefits of risk reduction. She previously was a senior research scientist at the U.S. Geological Survey in Menlo Park, California, where she served, among other positions, as chief scientist of the Western Earthquake Hazards team. Her research interests include the relationship between active faulting, deformation and state of stress in the earth's crust, quantifying earthquake likelihood, and characterizing natural-hazard risk.

Dr. Zoback has served on numerous national committees and panels on topics ranging from increasing the nation's resilience to disasters, defining the next generation of Earth observations from space, storing high-level radioactive waste, facilitating interdisciplinary research, and science education. From 1997 to 2000, she was a member of the National Research Council's Board on Radioactive Waste Management.

In 2007, she received from the Geological Society of America (GSA) both the Day Medal "for outstanding distinction in contributing to geologic knowledge through the application of physics and chemistry to the solution of geologic problems" and their Public Service Award. In 2002, she was awarded the Department of Interior Meritorious Service Award, and in 1987, she received the James B. Macelwane Award of the American Geophysical Union (AGU) for "significant contributions to the geophysical sciences by a young scientist of outstanding ability."

In 1995, Dr. Zoback was elected a member of the U.S. National Academy of Sciences (NAS). She is a member of the AGU and the Seismological Society of America, and is a past president of GSA. Dr. Zoback also is past chair of the Advisory Committee for San Francisco's Community Action Plan for Seismic Safety program. She is a member of the NAS Disaster Roundtable and the Advisory Committee for the National Earthquake Hazard Reduction Program.

Dr. Zoback received a Ph.D. in 1978, an M.S. in 1975, and a B.S. in 1974, all in geophysics and all from Stanford University.

Dr. Zoback resides in Stanford, California.

Appendix B

Strategic Plan—2014–2018

U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

STRATEGIC PLAN
FISCAL YEARS 2014-2018
MARCH 2014

U.S. Nuclear Waste Technical Review Board

Strategic Plan

Fiscal Years 2014-2018

U.S. Nuclear Waste Technical Review Board

Message From the Chairman

March 2014

In accordance with the Government Performance and Results Modernization Act of 2010, it is my pleasure to present the U.S. Nuclear Waste Technical Review Board's *Strategic Plan for Fiscal Years 2014 - 2018*. This plan supersedes the Board's *Strategic Plan for Fiscal Years 2011 - 2016*, which was published in 2010. The updated plan describes the Board's mission and the vision and values that underlie the Board's work and the development of the Board's Strategic Goals and Objectives.

As an independent Federal agency in the Executive Branch, the Board is committed to effectively carrying out its legislative mandate to "… evaluate the technical and scientific validity of the Department of Energy's activities related to managing and disposing of spent nuclear fuel and high-level radioactive waste." The Board's *Strategic Plan for Fiscal Years 2014 - 2018* provides a roadmap to guide us in achieving our Strategic Goals and Objectives and a benchmark, against which to evaluate the Board's performance in meeting those Goals and Objectives in the years ahead.

Rodney C. Ewing
Chairman

U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

STRATEGIC PLAN

FISCAL YEARS 2014-2018

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U.S. Nuclear Waste Technical Review Board
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Mission

The U.S. Nuclear Waste Technical Review Board was established in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) (P.L. 100-203) to "...evaluate the technical and scientific validity of activities [related to managing and disposing of spent nuclear fuel and high-level radioactive waste] undertaken by the Secretary [of Energy], including

(1) site characterization activities; and

(2) activities relating to the packaging or transportation of high-level radioactive waste or spent nuclear fuel."

As recorded in the Legislative History of the NWPAA, the purpose of the Board is to provide independent expert advice to Congress and the Secretary of Energy on technical and scientific issues and to review the technical and scientific validity of the U.S. Department of Energy's (DOE) implementation of the Nuclear Waste Policy Act (NWPA) (P.L. 97-425, as amended). In accordance with this mandate, the Board conducts objective, ongoing, and integrated technical and scientific peer review of DOE activities related to the management and disposition of commercial spent nuclear fuel (SNF) and of DOE SNF and high-level radioactive waste (HLW). The Board reports its findings, conclusions, and recommendations to Congress and the Secretary of Energy at least twice yearly.

Vision

By performing ongoing and independent technical and scientific peer review of the highest quality, the Board makes a unique and essential contribution to increasing confidence in the technical and scientific validity of DOE activities related to the management and disposition of SNF and HLW and to informing, from a technical and scientific perspective, policy discussions undertaken by decision-makers on options for managing and disposing of SNF and HLW. The Board provides objective and relevant technical and scientific information to Congress, the Administration, DOE, and the public on a wide-range of technical and scientific issues related to the management and disposition of such waste.

Values

The Board's conduct of its technical and scientific peer review reflects the following values:

- **Objectivity**. Board members have no real or perceived conflicts of interest related to the Board's mission. Board findings and recommendations are based on impartial evaluations of the technical and scientific validity of the Secretary's activities.

- **Openness**. Board deliberations are transparent and are conducted in such a way that the Board's integrity and objectivity are above reproach. The Board encourages public comment and discussion of Board findings, conclusions, and recommendations.

- **Technical and Scientific Competence**. Board findings, conclusions, and recommendations are technically and scientifically sound and are based on the best available technical and scientific information and analyses.

- **Timeliness**. Board findings, conclusions, and recommendations are communicated clearly and in time for them to be useful to Congress, the Secretary, and the public.

MEMBERS

The Board is composed of eleven members who are appointed by the President from a list of nominees submitted by the National Academy of Sciences (NAS). Nominees to the Board must be eminent in a field of science or engineering and are selected solely on the basis of established records of distinguished service. The Board is nonpartisan and apolitical. By law, no nominee to the Board may be an employee of DOE, of a National Laboratory under contract to DOE, or of an entity performing HLW or SNF activities under contract to DOE.

POWERS

The NWPAA grants significant investigatory powers to the Board: "The Board may hold such hearings, sit and act at such times and places, take such testimony, and receive such evidence as it considers appropriate." At the request of the Board, and subject to existing law, DOE is required to provide all records, files, papers, data, and information necessary for the Board to conduct its technical review, including drafts of work products and documentation of work-in-progress. According to the Legislative History of the NWPAA, Congress provided such access to allow the Board to review and comment on DOE decisions, plans, and actions as they occur, not after the fact.

HISTORY AND CONTINUING ROLE

For more than 20 years, DOE focused on developing a deep geologic repository for the permanent disposal of SNF and HLW at Yucca Mountain in Nevada. Throughout this period, the Board provided technical and scientific findings, conclusions, and recommendations on the technical and scientific validity of DOE's efforts. DOE submitted a license application (LA) for the Yucca Mountain repository to the U.S. Nuclear Regulatory Commission (NRC) in June 2008. In early 2010, DOE petitioned the NRC for permission to withdraw the LA. Also in early 2010, then Secretary of Energy Steven Chu appointed the Blue Ribbon Commission on America's Nuclear Future (BRC) to consider alternatives for managing the back end of the nuclear fuel cycle. The BRC submitted its recommendations to the Secretary in January 2012, and DOE issued its *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* one year later. In August 2013, the U.S. Court of Appeals for the DC Circuit ruled that NRC must resume its review of the Yucca Mountain license application.

Even as options for managing nuclear waste are evaluated, DOE continues to have responsibility under the NWPA for the management and disposition of SNF and HLW. Similarly, the Board's statutory responsibility for conducting ongoing technical and scientific peer review of these DOE activities and for advising Congress and the Secretary on technical and scientific issues related to nuclear waste management and disposal remains unchanged.

STRATEGIC GOALS

The Board has established the following Strategic Goals to guide the implementation of its Mission:

- The Board will help enhance the technical and scientific validity of DOE activities related to implementing the NWPA.
- The Board will help inform, from a technical perspective, policy discussions and decision-making related to managing and disposing of SNF and HLW.

The Goals are used to allocate resources and guide internal decision-making related to accomplishing Board priorities and improving outcomes.

STRATEGIC OBJECTIVES

In line with its Strategic Goals, the Board has developed three Strategic Objectives for fiscal years (FY) 2014-2018. The Strategic Objectives reflect the Board's continuing technical and scientific evaluation of activities undertaken by DOE's Office of Nuclear Energy (DOE-NE) related to managing and disposing of commercial SNF and activities undertaken by the Office of Environmental Management (DOE-EM) related to disposing of DOE's SNF and HLW.

During FY 2014-2018:

- The Board will continue its ongoing technical and scientific evaluation of DOE activities related to implementation of the NWPA. Based on its evaluation, the Board will report its findings, conclusions, and recommendations to Congress and the Secretary.
- The Board will develop objective technical and scientific information to advise Congress and the Secretary on issues related to SNF and HLW management and disposal. The Board will communicate such information in reports, correspondence, and testimony.
- The Board will compile technical and scientific information and report to Congress and the Secretary on its findings, conclusions, and recommendations from experience gained over more than twenty years of reviewing the U.S. nuclear waste management and disposal program and from observing waste management efforts in other countries.

ACHIEVING THE STRATEGIC GOALS AND OBJECTIVES

- **Authority under the Law.** The Board has the necessary authority, under current law, to achieve its Strategic Goals and Objectives.

- **Establishing the Strategic Objectives and Annual Performance Goals.** The Board's Strategic Objectives are established in the Strategic Plan. The Board also identifies, on an annual basis, shorter-term Performance Goals that will lead to the accomplishment of the Strategic Objectives and includes the Strategic Objectives and Performance Goals in its annual Performance Plan.

- **Technical Analysis.** Analysis of technical information is performed by Board members with assistance from a small, full-time senior professional staff. On the basis of these analyses, the Board reports its findings and recommendations to Congress and the Secretary of Energy. When necessary, the Board is authorized to hire expert consultants to support its in-depth reviews of specific technical and scientific topics.

- **Evaluating Board Performance.** The Board includes in its annual Budget Submittal an evaluation of the Board's performance in achieving its annual Performance Goals for the preceding year. The process for evaluating Board performance is discussed below. Progress toward achieving the Board's Performance Goals is reviewed quarterly by Board management, and appropriate actions are taken to facilitate the achievement of the goals during the time period. This information is taken into account in developing the Board's annual budget submittal.

- **Coordinating and Focusing Board Activities.** Board members are assigned by the Chairman to lead or participate in Board activities, as appropriate. The work of the Board members is supported by the Board's senior professional staff. The Board maintains the option of organizing panels or working groups of Board members and staff members to help facilitate, integrate, and focus its technical review, and for other purposes.

- **Information Gathering.** Much of the Board's peer review and information gathering takes place at the Board's open public meetings where technical information is presented by representatives of DOE and of other relevant organizations according to an agenda prepared by the Board. Following the presentations, Board members and staff question presenters on related technical issues, and time is provided at the meetings for input and comments from interested members of the public. The Board holds two or three public meetings each year. Board panels and other small groups of Board members and staff hold other meetings, as needed, to investigate specific technical and scientific topics. The Board's public meetings are announced in the *Federal Register*, typically four to six weeks before the meetings are held.

  The Board also gathers information from site visits, visits to national laboratories and facilities, and meetings with DOE and national laboratory and contractor staff working on relevant projects and programs. Board members and staff attend national and international technical and scientific symposia and conferences related to SNF and HLW management and disposition. From time to time, Board members and staff travel to other countries to meet with representatives of organizations involved in the management of SNF and HLW to observe their technical and scientific programs, discuss best practices, perform benchmarking, and assess potential analogs, among other things. The information gathered is used to inform the Board's technical and scientific review of DOE programs and to advise Congress.

- **Involving the Public**. In conducting its on-going technical and scientific peer review, the Board provides extensive opportunities for public participation at its open public meetings. Over the years, the Board's meetings have become a unique forum for the interested public to interact directly with the Board and its staff; DOE managers, scientists, engineers, and consultants; and other program participants. Public comments offered at the meetings are included in meeting transcripts, and written public comments and other materials submitted in conjunction with the meetings are included in the meeting records on the Board's website.

- **Communicating Board Findings, Conclusions, and Recommendations.** On the basis of the Board's evaluations and other evidence, the Board reports its technical and scientific findings, conclusions, and recommendations to Congress and the Secretary of Energy. The Chairman and other members of the Board and Board staff testify before Congress, as requested. As discussed above, all Board reports, testimony, correspondence, and meeting agendas, transcripts, presentations, and public comments are posted on the Board's website at www.nwtrb.gov.

Crosscutting Functions

Many organizations and entities are involved in some aspect of managing and disposing of SNF and HLW, including, but not limited to, Congress, DOE, the NRC, the Environmental Protection Agency, the Department of Transportation, the NAS, the Government Accountability Office, affected Native American Tribes, Affected Units of Local Government, the National Association of Regulatory Utility Commissioners, the National Governors' Association and regional governors' groups, the National Conference of State Legislatures, the Nuclear Energy Institute, the Electric Power Research Institute, and environmental organizations, such as the Natural Resources Defense Council.

The Board's technical and scientific evaluation is at once different from and complementary to the activities of most of these entities. The Board is (1) unconstrained by any stake, beyond technical and scientific validity, in the outcome of the activities it reviews; (2) limited by its statutory mandate to reviewing the technical and scientific validity of DOE activities (not the policy implications or regulatory compliance); and (3) a permanent independent federal agency whose members are appointed by the President.

Key External Factors

As discussed below, factors that are outside the Board's control could affect the Board's ability to achieve its Strategic Goals or Objectives.

- *The Board has no statutory authority to implement its recommendations.* The Board is a technical and scientific peer-review body that makes findings, conclusions, and recommendations. The Board's enabling statute does not obligate DOE to comply with Board recommendations. However, according to the Legislative History of the NWPAA, Congress expected that DOE would accept Board recommendations or indicate why the recommendations could not or should not be implemented. If DOE does not accept a Board recommendation, the Board can reiterate its recommendation, advise Congress, or both.

- *Funding levels may not be consistent or may be insufficient for the Board to fully meet its performance goals on the timetable planned.* Funding constraints can affect the Board's ability to complete its review of DOE activities and provide its technical and scientific findings, conclusions, and recommendations to Congress and the Secretary of Energy in accordance with its annual Performance Goals. Funding levels and allocation decisions may affect the nature and extent of activities undertaken by DOE that are subject to the Board's ongoing technical and scientific review, which also may affect the Board's activities and schedules.
- *Administrative, judicial, or legislative actions may alter nuclear waste policy.* As discussed above, the U.S. Court of Appeals for the DC Circuit has ruled that NRC must resume its review of the Yucca Mountain license application, and most DOE activities related to implementing the NWPA have transitioned from the now defunct Office of Civilian Radioactive Waste Management to DOE-NE. Most activities related to the management and disposal of DOE SNF and all the activities related to the management and disposal of HLW are the responsibility of DOE-EM. Decisions or activities undertaken by any of these entities could affect the nature or extent of the Board's technical and scientific review.

The Board's ongoing technical and scientific peer review is especially important in enhancing confidence in the technical and scientific process during periods of uncertainty. The Board will continue to evaluate the status of these external factors, identify any new factors, and, if necessary, update its Strategic Objectives and Performance Goals as appropriate.

EVIDENCE-BASED EVALUATION OF BOARD PERFORMANCE

The Board's progress in meeting its Strategic Objectives and annual Performance Goals is evaluated quarterly, and adjustments are made, as necessary. At the end of the fiscal year, the Board's performance in achieving its annual Performance Goals is reported in its annual Budget Submittal. The Board uses the evaluation of its performance as input in revising, as necessary, its Strategic Objectives and in developing its annual Performance Goals for the following fiscal year.

The reliability of the evidence and data used to evaluate the Board's performance in relation to its annual Performance Goals is high and can be verified by accessing the referenced documents and the records of meetings on the Board's website at www.nwtrb.gov.

TRANSPARENCY

In developing its Strategic Plan for FY 2014-2018, the Board will solicit comments from OMB, Congress, DOE, and members of the public and will provide electronic copies of the Strategic Plan to NRC, NAS, and other interested parties. The Strategic Plan will be posted on the Board's website.

Appendix C

Board Publications

Board Publications

Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program
January 2016

This report is based on the Board's evaluation of information presented by the U.S. Department of Energy (DOE) and subject matter experts from the United States and other countries at a Board workshop on deep borehole disposal held in Washington, DC on October 20–21, 2015. In the report, the Board makes technical and scientific findings, conclusions, and recommendations on two topics: (1) technical and scientific issues that may affect the feasibility of the deep borehole disposal option for select radioactive waste forms, and (2) whether results that will be obtained from the DOE Deep Borehole Field Test will provide the necessary technical data and scientific understanding for determining the feasibility of disposing of some radioactive waste forms in deep boreholes.

Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Overview and Summary
November 2015

To provide information about efforts in the United States and other countries to site a deep-mined, geologic repository for high-level radioactive waste (HLW) and spent nuclear fuel (SNF), the Board prepared two reports that rely on a comparative historical inquiry into two dozen siting efforts that have taken place over the past half century in ten different countries. The *Overview and Summary* provides a short synopsis of the major insights that derive from that study. The *Detailed Analysis*, referred to below, is an in-depth account that provides the empirical foundations for those insights. The reports contain four recommendations that policymakers might consider if they choose to begin a new siting effort for a first or second repository.

Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis
November 2015

To provide information about efforts in the United States and other countries to site a deep-mined, geologic repository for HLW and SNF, the Board prepared two reports that rely on a comparative historical inquiry into two dozen siting efforts that have taken place over the past half century in ten different countries. The *Overview and Summary*, referred to above, provides a short synopsis of the major insights that derive from that study. The *Detailed Analysis* is an in-depth account that provides the empirical foundations for those insights. The reports contain four recommendations that policymakers might consider if they choose to begin a new siting effort for a first or second repository.

Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel
June 2015

The report is based on the Board's review of DOE reports and studies supporting a new DOE initiative involving the development of two mined geologic repositories: one to dispose of defense HLW and possibly some DOE-managed SNF, and another to dispose of commercially generated HLW and SNF, together with other DOE-managed HLW and SNF. The new initiative also includes consideration of options for disposal of smaller DOE-managed waste forms in deep boreholes. In the report, the Board makes technical and scientific findings, conclusions, and recommendations related to the implementation of DOE's new initiative.

A Report to the U.S. Congress and the Secretary of Energy—Board Activities, January 1, 2008–December 31, 2012
December 2014

The report is one in a series of summary reports issued periodically since the beginning of Board operations in 1989 that chronicle Board activities over a defined period of time. The report is archival in nature and does not break new ground. Rather, it documents Board activities, findings, and recommendations for the reporting period. The five years covered by the report were consequential for the Board and for the U.S. program to manage and dispose of SNF and HLW.

Review of U.S. Department of Energy Activities to Preserve Records Created by the Yucca Mountain Repository Project
August 2013

The report chronicles the Board's review of DOE efforts to preserve records developed over almost thirty years by the Yucca Mountain Repository Project. In 2010, funding for the repository program was eliminated, and DOE notified the Nuclear Regulatory Commission of DOE's intention to withdraw the Yucca Mountain license application. At that point, responsibility for archiving and preserving Yucca Mountain scientific and engineering information was transferred to DOE's Office of Legacy Management. In 2010, the Board began evaluating DOE activities related to archiving and preserving Yucca Mountain data and information as part of its ongoing technical and scientific review and in response to direction from the House Committee on Appropriations.

Nuclear Waste Assessment System for Technical Evaluation (NUWASTE): Status and Initial Results
June 2011

The report describes work performed by the Board to evaluate the effects of SNF and HLW management on various fuel-cycle options being considered at that time by the DOE. Of particular interest to the Board were the types and quantities of radioactive waste streams that would be generated. The Board developed a computer-based systems analysis tool, the Nuclear Waste Assessment System for Technical Evaluation

(NUWASTE), to support its technical evaluation of DOE activities in this area. Included in the report are initial findings from NUWASTE analyses.

Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Wastes: Lessons Learned from Yucca Mountain and Other Programs
June 2011

The purpose of this report was to extract and record technical and scientific knowledge, while still available, from the Yucca Mountain deep geologic repository program and programs in other countries for managing SNF and HLW. In this report, the Board examines the history of the Yucca Mountain program and several other nuclear waste programs from a technical perspective, and discusses technical information and insights that may be useful for future U.S. efforts to manage and dispose of SNF and HLW.

Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries
April 2011

This report explores the efforts of thirteen nations to find a permanent solution for isolating HLW and SNF generated within their borders. It builds on information in the Board's 2009 *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*. Unlike the earlier document, however, this report describes the programs and their histories, and discusses inferences that can be drawn from their experiences.

Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel—Executive Summary
December 2010

The report was prepared to inform DOE and Congress about the current state of the technical basis for extended dry storage of SNF and for subsequent SNF transportation.

Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel
December 2010

The report presents an overview of available public literature on SNF storage and handling, and the safety of extended SNF dry storage and subsequent transportation.

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel
October 2009

The report describes thirty technical and institutional attributes of nuclear waste programs in thirteen countries. It does not make judgements; rather, the report provides factual information for Congress and the Secretary of Energy that can be used for evaluating waste management options.

Letter Report to Congress and the Secretary of Energy
October 27, 2009

This report in letter form updates Congress and the Secretary of Energy on the mission, continuing role, and refocused goals of the U.S. Nuclear Waste Technical Review Board as the U.S. approach to managing SNF and HLW undergoes an evolution.

Report to Congress and the Secretary of Energy
September 2008

The report is one in a series of summary reports issued periodically since the beginning of Board operations in 1989 that chronicle the Board's activities over a defined period of time. This report focused on Board activities from March 1, 2006, to December 31, 2007. During that time, the Board evaluated critical technical issues that deal with the waste management system, including preclosure operations and postclosure performance of the proposed Yucca Mountain repository, and the cross-cutting issue of thermal management.

Technical Evaluation of U.S. Department of Energy Yucca Mountain Infiltration Estimates: A Report to Congress and the Secretary of Energy
December 2007

In this report, the Board presents its evaluation of revised U.S. Department of Energy estimates of water infiltration at Yucca Mountain. The infiltration estimates were revised because violations of quality assurance procedures were alleged to have been committed by U.S. Geological Survey employees who were involved in gathering and analyzing infiltration data at Yucca Mountain in the 1990s.

Report to Congress and the Secretary of Energy
January 2007

This report contains summaries of Board findings and recommendations contained in the following: letters to the director of the Office of Civilian Radioactive Waste Management (OCRWM) following Board meetings held in February, May, and September 2006; a letter and enclosures sent to OCRWM following a Board workshop on deliquescence-induced localized corrosion in September 2006; and testimony the Board's Chairman presented in May 2006 before the Senate Energy and Natural Resources Committee.

Report to Congress and the Secretary of Energy
June 2006

In this report, the Board summarizes its major activities from January 1, 2005, through February 28, 2006. During that period, the Board focused its attention on the DOE's efforts to develop postclosure performance estimates for the proposed repository at Yucca Mountain in Nevada. Correspondence and related materials are included in the appendices to the report, along with the Board's strategic plan for fiscal years 2004 through 2009, its performance plans for fiscal years 2005 and 2006, and its performance evaluation for 2005.

Letter Report to Congress and the Secretary of Energy
December 2005

In this letter report to Congress and the Secretary of Energy, the Board presents its views on the status of some important issues related to the technical basis for U.S. Department of Energy activities for designing the nuclear waste management system, including the engineered system, the natural system, the repository system, and the assessment of the performance of the systems. The Board also outlines issues that it expects may continue to be of interest in the future.

Report to Congress and the Secretary of Energy
May 2005

In this report, the Board summarizes its major activities from January 1, 2004, through December 31, 2004. During that period, the Board focused on the Department of Energy's efforts to develop a system for accepting, transporting, and handling HLW and SNF before disposal in the repository proposed for Yucca Mountain. Correspondence and related materials are included in the appendices to the report, along with the Board's strategic plan for fiscal years 2004 through 2009, its performance plans for 2005, and its performance evaluation for 2004.

Letter Report to Congress and the Secretary of Energy
December 2004

This letter and enclosure comprise the Board's second report to Congress and the Secretary of Energy for calendar year 2004. The letter briefly summarizes areas where the Board believes DOE made progress, areas requiring attention, and the Board's priorities for the coming year. The enclosure contains a more detailed discussion of those topics.

Report to Congress and the Secretary of Energy
May 2004

In this report, the Board summarizes its major activities from January 1, 2003, through December 31, 2003. During that period, the Board continued its evaluation of DOE activities and held meetings on a range of technical and scientific issues, including seismicity, DOE plans for transporting SNF and HLW, the design and operation of facilities at the Yucca Mountain proposed repository site, performance confirmation activities, and the potential for localized corrosion. Correspondence and related materials are included in the appendices to the report, along with the Board's strategic plan for fiscal years 2004 through 2009, its performance plans for 2004 and 2005, and its performance evaluation for 2003.

Report to Congress and the Secretary of Energy
December 19, 2003

This report and attachments constitute the Board's second report to Congress and the Secretary of Energy for calendar year 2003. It is composed of letters on localized corrosion sent to the Director of the Office of Civilian Radioactive Waste Management on October 21, 2003, and November 25, 2003.

Board Technical Report on Localized Corrosion
November 25, 2003

This technical document supports Board conclusions in its October 21, 2003, letter to the U.S. Department of Energy on the potential for localized waste package corrosion during the thermal pulse.

Report to the Secretary of Energy and the Congress
April 2003

This report summarizes the Board's major activities between January 1, 2002, and December 31, 2002. During this period, the Board focused on evaluating the technical basis of DOE's work on analyzing a planned repository site at Yucca Mountain in Nevada. Included in an appendix to the report are letters to DOE on technical issues the Board identified as part of its ongoing review in 2002. Also included in the appendices are the Board's strategic plan for fiscal years 2003 through 2008, its performance plans for 2003 and 2004, and its performance evaluation for 2002.

Report to the Secretary of Energy and the Congress
April 2002

This report summarizes the Board's major activities between February 1, 2001, and January 31, 2002. During this period, the Board focused on evaluating the technical basis of DOE's work on a Yucca Mountain site recommendation, including DOE's characterization of the Yucca Mountain site, DOE's design of the repository and waste packages, and the estimates of how a repository system developed at the site might perform. The report includes a description of activities the Board undertook to develop its assessment of the technical basis for the DOE's repository performance estimates.

Letter Report to Congress and the Secretary of Energy
January 24, 2002

This letter report summarizes the Board's technical and scientific evaluation of the DOE's investigations and assessments supporting its recommendation of the Yucca Mountain site as a potential location for a deep-mined, geologic repository for SNF and HLW.

Proceedings from an International Workshop on Long-Term Extrapolation of Passive Behavior, Arlington, Virginia, July 19–20, 2001
December 2001

This is a compilation of submissions to a Board workshop on issues predicting corrosion behavior for periods of unprecedented duration. The workshop was held on July 19–20, 2001, in Arlington, Virginia. A panel of three Board members and fourteen internationally recognized corrosion scientists, eight of whom were from outside the United States, participated in the workshop. Afterward, most panelists submitted papers with their views on issues related to predicting very long-term corrosion.

Report to the Secretary of Energy and the Congress
April 2001

In this report, the Board summarizes its views on four priority areas for evaluating the potential repository at Yucca Mountain:

- Meaningful quantification of conservatisms and uncertainties in the U.S. Department of Energy's performance assessments.
- Progress in understanding the underlying fundamental processes involved in predicting the rate of waste-package corrosion.
- Evaluation and comparison of the base-case repository design with a low-temperature design.
- Development of multiple lines of evidence to support the safety case of the proposed repository, the lines of evidence being derived independently of performance assessment and thus not being subject to the limitations of performance assessment.

Letter Report to the Secretary of Energy and the Congress
December 2000

This letter report presents a brief update of the Board's views on the status of the U.S. Department of Energy's repository development program.

Report to the U.S. Congress and the Secretary of Energy
April 2000

In this report, the Board summarizes its major activities in calendar year 1999. Among the activities discussed is the Board's 1999 review of DOE's viability assessment (VA) of the Yucca Mountain site. The Board's evaluation of the DOE VA concludes that Yucca Mountain continues to warrant study as the candidate site for a permanent geologic repository and that work should proceed to support a decision on whether to recommend the site for repository development. The Board suggests that the 2001 date for a decision is very ambitious and that focused study should continue on natural and engineered barriers. The Board states that a credible technical basis does not currently exist for the above-boiling repository design included in the VA. The Board recommends evaluation of alternative repository designs, including lower-temperature designs, as a potential way to help reduce the many uncertainties related to predictions of repository performance.

Report to the U.S. Congress and the Secretary of Energy
April 1999

In this report, the Board summarizes its major activities during calendar year 1998. The report discusses the research needs identified in DOE's recently issued VA of the Yucca Mountain site, including plans to gather information on the amount of water that will eventually seep into repository drifts, whether formations under the repository will retard radionuclide migration, the flow-and-transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon, and long-term corrosion rates of materials that may be used for the waste packages. The report describes other activities the Board undertook in 1998, including a review of the hypothesis that there were hydrothermal upwellings at Yucca Mountain, a workshop held to increase understanding of the range of expert opinion on waste package materials, and a review of the DOE's draft environmental impact statement for the Yucca Mountain site.

Report to the U.S. Congress and the Secretary of Energy: Moving beyond the Viability Assessment
April 1999

In this report, the Board presents its views on DOE's December 1998 VA of the Yucca Mountain site in Nevada. The Yucca Mountain site is being characterized to determine its suitability as the location of a permanent repository for disposing of SNF and HLW. The Board discusses the need to address key uncertainties that remain about the site, including the performance of the engineered and natural barriers. The Board addresses DOE's plans for reducing those uncertainties and suggests that consideration be given to alternative repository designs, including ventilated low-temperature designs that have the potential to reduce uncertainties and simplify the analytical bases for determining site suitably and for licensing. The Board also comments on DOE's total system performance assessment, the analytical tool that pulls together information on the performance of the repository system.

Report to the U.S. Congress and the Secretary of Energy
November 1998

In this report, the Board presents its views on the direction of future scientific and technical research under way and planned by the U.S. Department of Energy as part of its program for characterizing a site at Yucca Mountain in Nevada as a potential repository for SNF and HLW. The Board discusses some of the remaining key scientific and technical uncertainties related to performance of a potential repository. The report addresses some of these uncertainties by examining information about the proposed repository system presented at Board meetings and other technical exchanges. The Board comments on some of the important connections between the site's natural properties and the current designs for the waste package and other engineered features of the repository.

Letter Report: Board Completes Review of Material on Hydrothermal Activity
July 24, 1998

This letter and attachments presents the Board's review of material related to Mr. Jerry Szymanski's hypothesis of ongoing, intermittent hydrothermal activity at Yucca Mountain and large earthquake-induced changes in the water table there. The report includes a cover letter, the Board's review, and the reports of the four consultants with whom the Board contracted to assist in the review.

1997 Findings and Recommendations
April 1998

This report details the Board's technical and scientific evaluation in 1997 of DOE's activities, including the development of DOE's VA, due in September 1998; underground exploration of the candidate repository site at Yucca Mountain in Nevada; thermal testing under way at the site; what happens when radioactive waste reaches the water table beneath Yucca Mountain; SNF transportation; and using expert judgment. The Board makes four recommendations in the report, concerning (1) the need for DOE to begin now to develop alternative design concepts for a repository, (2) the need for DOE to include estimates of the likely variation in doses for alternative candidate critical groups in its interim performance measure for Yucca Mountain, (3) the need for DOE to evaluate whether site-specific biosphere data is needed for a license application, and (4) the need for DOE to make full and effective use of formally elicited expert judgment.

Letter Report to the Secretary of Energy and the Congress
December 23, 1997

This letter report addresses several key issues, including DOE's VA of the Yucca Mountain site, design of the potential repository and waste package, the total system performance assessment, and the enhanced characterization of the repository block.

Report to the U.S. Congress and The Secretary of Energy: 1996 Findings and Recommendations
March 1997

This report summarizes Board activities during calendar year 1996. Chapter 1 provides an overview of DOE's high-level waste management program from the Board's perspective, including the viability assessment, program status, and progress in exploration and testing. Chapter 2 examines three technical issues—hydrology, radionuclide transport, and performance assessment—and provides conclusions and recommendations. Chapter 3 deals with the repository system, including underground operations, thermal loading, and engineered barriers. Also discussed are the repository layout, design alternatives, and construction planning. Chapter 4 provides an overview of recent Board activities, including an international exchange of information on repository programs, the Board's visit to the River Mountains tunnel, and a presentation to the Nuclear Regulatory Commission.

Nuclear Waste Management in the United States—The Board's Perspective
June 1996

This document contains a talk by Board Chairman John Cantlon delivered at Topseal '96, an international conference on nuclear waste management and disposal. The conference was sponsored by the Swedish Nuclear Fuel and Waste Management Company and the European Nuclear Society. The publication highlights Dr. Cantlon's views on the status of the U.S. repository program, including DOE efforts to characterize the Yucca Mountain site and to develop a waste isolation strategy. The publication also describes legislative and regulatory changes under consideration at that time and the technical implications of those potential changes.

Report to the U.S. Congress and the Secretary of Energy: 1995 Findings and Recommendations
April 1996

This report summarizes Board activities during calendar year 1995. Chapter 1 provides an overview of the U.S. Department of Energy's high-level waste management program, including highlights, current status, legislative issues, milestones, and Board recommendations. Chapter 2 reports on Board panel activities, and Chapter 3 provides information on new Board members, meetings attended, interactions with Congress and congressional staff, Board presentations to other organizations, interactions with foreign programs, and a review of the Board's report on SNF interim storage.

Disposal and Storage of Spent Nuclear Fuel—Finding the Right Balance
March 1996

This special report caps more than two years of study and analysis by the Board into the issues surrounding interim storage of commercial SNF and the timing of developing a federal centralized storage facility. The Board suggests in the report that the U.S. Department of Energy should remain focused on permanent geologic disposal and the site investigations at Yucca Mountain in Nevada. Planning for a federal centralized SNF storage facility and the required transportation infrastructure should begin early, but actual construction of a facility should be delayed until after a site-suitability decision is made on the Yucca Mountain site.

Letter Report to the Secretary of Energy and the Congress
December 13, 1995

This letter report discusses DOE's progress in exploring the underground at Yucca Mountain with a tunnel boring machine, advances in developing a waste isolation strategy for the proposed repository, recent DOE work on engineered barrier design, and DOE activities related to repository performance assessment.

Report to the U.S. Congress and the Secretary of Energy: 1994 Findings and Recommendations
March 1995

This report summarizes Board activities during calendar year 1994. It covers aspects of DOE's program approach, the DOE's emerging waste isolation strategy, and the DOE's transportation program. It explores the Board's views on minimum exploratory requirements and thermal-loading issues for the repository. A chapter of the report focuses on the lessons learned on site assessment from high-level waste disposal projects around the world. Another chapter deals with volcanism and problem resolution. The Board also presents observations from its visit to Japan and the Japanese nuclear waste disposal program. Board findings and recommendations in the report center on structural geology and geoengineering, hydrogeology and geochemistry, the engineered barrier system, and risk and performance analysis.

Report to the U.S. Congress and the Secretary of Energy: January to December 1993
May 1994

The report summarizes Board activities, primarily during 1993. The Board reports on nuclear waste disposal programs in Belgium, France, and the United Kingdom; elaborates on the Board's understanding of the radiation protection standards being reviewed by the National Academy of Sciences; and, using "future climates" as an example, examines DOE's approach to "resolving difficult issues." Recommendations center on the need for a systems approach in implementing DOE Office of Radioactive Waste Management programs, setting priorities among site-suitability activities, appropriate use of total system performance assessment and expert judgment, and the dynamics of the Yucca Mountain ecosystem.

Letter Report to Congress and the Secretary of Energy
February 1994

The letter report restates a recommendation made in the Board's 1993 *Special Report* that an independent review of the Office of Civilian Radioactive Waste Management's management and organizational structure be initiated as soon as possible. The letter report adds two recommendations: sufficient and reliable funding should be ensured for site characterization and performance assessment, whether the program budget remains level or is increased, and DOE's decision-making process on siting a Yucca Mountain repository should take into account the views of various stakeholders.

Underground Exploration and Testing at Yucca Mountain, A Report to Congress and the Secretary of Energy
October 1993

This report focuses on the exploratory studies facility at Yucca Mountain in Nevada, including the conceptual design, planned exploration and testing, and excavation plans and schedules. In addition to a number of detailed recommendations, the Board makes three general recommendations. First, DOE should develop a comprehensive strategy that integrates exploration and testing priorities with the design and excavation approach for the exploratory facility. Second, underground thermal testing should be resumed as soon as possible. Third, DOE should establish a geoengineering board with expertise in engineering, constructing, and managing large underground projects.

Special Report to Congress and the Secretary of Energy
March 1993

This report discusses institutional and policy issues that potentially affect the technical and scientific credibility of DOE's repository program. Three important issues are presented: first, the repository program is driven by unrealistic deadlines; second, the repository program lacks an integrated waste management plan; and third, program management needs to be improved. To address these issues, the Board makes the following recommendations: amend the current schedule to include realistic intermediate milestones; develop a comprehensive, well-integrated plan for overall management of all SNF and HLW from generation to disposal; and implement an independent evaluation of the organization and management of DOE's Office of Civilian Radioactive Waste Management. The Board notes that the recommendations should be implemented without slowing the progress of site-characterization activities at Yucca Mountain.

Sixth Report to the U.S. Congress and the U.S. Secretary of Energy
December 1992

The report summarizes recent Board activities, congressional testimony, changes in Board makeup, and the effects of the Little Skull Mountain earthquake. Chapter 2 details panel activities and offers seven technical recommendations on the dangers of a schedule-driven program, including the need for top-level systems studies; consideration of the impact of defense HLW; the use of high-capacity, self-shielded waste package designs; and the need for setting priorities among the numerous studies in the site-characterization plans. In Chapter 3, the Board offers candid insights on the high-level waste management program in five countries, specifically those issues that might be applicable to the U.S. program, including program size and cost, utility responsibilities, repository construction schedules, and alternative approaches to licensing. Appendix F provides background on the Finnish and Swiss programs.

Fifth Report to the U.S. Congress and the Secretary of Energy
June 1992

The Board's fifth report focuses on thermal loading strategies in the United States and the importance and uncertainties of this cross-cutting issue. The report discusses the Board's position on the technical implications of thermal loading for the U.S. SNF and HLW management system. The report also includes updates on Board and panel activities during the reporting period. The Board makes recommendations in the report to DOE on the following subjects: the exploratory studies facility, repository design enhancements, repository sealing, seismic vulnerabilities (vibratory ground motion and fault displacement), DOE's approach to the engineered barrier system, and SNF and HLW transportation.

Fourth Report to the U.S. Congress and the U.S. Secretary of Energy
December 1991

The report explores in depth and makes recommendations on the following technical areas: exploratory studies facility construction; testing priorities; rock mechanics; tectonic features and processes; volcanism; hydrogeology and geochemistry in the unsaturated zone; the engineered barrier system; regulations promulgated by the U.S. Environmental Protection Agency, the U.S. Nuclear Regulatory Commission, and DOE; the DOE performance assessment program; and the quality assurance program for the Yucca Mountain project.

Third Report to the U.S. Congress and the U.S. Secretary of Energy
May 1991

The report describes Board activities and congressional testimony. Other topics include exploratory shaft facility design alternatives; repository design; risk-benefit analysis; waste package plans and funding; SNF corrosion; transportation and waste management systems; environmental program concerns; DOE task force studies on risk and performance assessment; federal quality assurance requirements for the repository program; and measuring, modeling, and applying radionuclide sorption data. The Board makes fifteen recommendations to DOE on these issues. Background information on the German and Swedish nuclear waste disposal programs is included in Appendix D of the report.

Second Report to the U.S. Congress and the U.S. Secretary of Energy
November 1990

The Board's second report establishes a framework for discussing repository development and makes specific technical and scientific recommendations concerning tectonic features and processes, geoengineering considerations, the engineered barrier system, transportation and systems, environmental and public health issues, and risk and performance analysis. The report also offers concluding perspectives on progress made by DOE, the state of Nevada's role, the project's regulatory framework, the nuclear waste negotiator, other oversight agencies, and the Board's future plans.

First Report to the U.S. Congress and the U.S. Secretary of Energy
March 1990

The first Board report sets the stage for the Board's evaluation of DOE's program to manage disposal of the nation's SNF and HLW. The report briefly outlines the legislative history of the SNF and HLW management program, including its legal and regulatory requirements. The Board's evolution is described, along with its protocol, panel structure, and reporting requirements. The report identifies major technical and scientific issues the Board identified for further evaluation and highlights five cross-cutting issues.

Appendix D

Congressional Testimony and Correspondence

Congressional Testimony and Correspondence

- *Statement of Dr. Rodney Ewing, Chairman, U.S. Nuclear Waste Technical Review Board; April 11, 2013*
  Subject: Testimony presented to the Subcommittee on Energy and Water Development, Committee on Appropriations, United States House of Representatives.
- *Letter from Dr. Rodney Ewing, Chairman, to Senator Ron Wyden, Chairman of the Senate Committee on Energy and Natural Resources; June 7, 2013*
  Subject: Board comments on draft comprehensive nuclear waste legislation.
- *Letter from Dr. Rodney Ewing, Chairman, to the Honorable Rodney Frelinghuysen, Chairman of the House Subcommittee on Energy and Water Development, Committee on Appropriations; September 16, 2013*
  Subject: Board comments on international and U.S. experience with consent-based siting of deep geologic repositories.

Statement of Rodney C. Ewing, Chairman
U.S. Nuclear Waste Technical Review Board

Before the

Subcommittee on Energy and Water Development
Committee on Appropriations
U. S. House of Representatives
April 11, 2013

Chairman Frelinghuysen, Ranking Member Kaptur, and members of the Subcommittee, good morning. My name is Rodney Ewing. I am Chairman of the U.S. Nuclear Waste Technical Review Board. I am also a professor in the Departments of Earth & Environmental Sciences, Nuclear Engineering & Radiological Sciences, and Materials Science & Engineering at the University of Michigan. Thank you for holding this hearing on nuclear programs and strategies. I appreciate being invited to discuss, from the Board's technical perspective, the following questions from the Subcommittee:

1. What do international and U.S. experiences tell us about consent-based siting?
2. What can we learn from Yucca Mountain, technically and otherwise?
3. What is the current thinking and consensus around preferable options for nuclear waste disposal and the siting of a geologic repository?

About the Board

Before I address those questions, I would like to briefly describe the Board and its role related to the management and disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW).

According to the Legislative History of the Nuclear Waste Policy Amendments Act (1987), which established the Board, the Board was created to be a source of objective, expert

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technical and scientific advice to Congress and the Secretary of Energy on nuclear waste issues and to review the technical and scientific validity of U.S. Department of Energy (DOE) activities related to implementing the 1982 Nuclear Waste Policy Act (NWPA), including the packaging, transportation, and disposal of SNF and HLW. The Board reports its findings, conclusions, and recommendations to Congress and the Secretary of Energy.

The Board prizes its independence and objectivity. The process for nominating and appointing Board members underscores and ensures the nonpolitical character of the Board; its 11 members are nominated by the National Academy of Sciences (NAS) solely based on their eminence and expertise and appointed by the President. I should note that the current Board is relatively new; all but three of the members were appointed this past September. The remaining three of us have been on the Board for less than two years.

The current focus of the Board's activities is the evaluation of technical and scientific work that DOE will undertake to implement its recently announced "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste." In particular, the Board will review DOE's disposal-related research that was noted in the Strategy, such as evaluating whether direct disposal of existing storage containers used at utility sites can be accomplished in a variety of geologic media; evaluating various types and design features of back-filled engineered barriers systems and materials; evaluating different types of geologic media for their impacts on waste isolation; evaluating thermal management options for various geologic media; and developing a research and development plan for deep borehole disposal. The Board also reviews DOE's work related to the disposal of DOE-owned SNF and HLW. We will be gathering information on that topic at a meeting, which will be held at Hanford next week.

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In addition to the work I just described, the Board is engaged in analysis of the following topics that we believe will provide useful technical and scientific information to program managers and decision-makers in Congress and at DOE who are involved in developing nuclear waste management policies.

- Office of Legacy Management's Preservation of Data and Information from the Yucca Mountain Project
- Consent-Based Repository-Siting Process: International Experience and Lessons Learned
- The System-Wide Implications of Repackaging SNF Currently in Dry-Storage at Nuclear Utility Sites
- A Survey of DOE-Owned SNF
- Issues Associated with Deep Borehole Disposal of SNF
- International Experience: Update and Expansion of the Board's Previous Report, *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*

I will now turn to the questions posed by the Subcommittee.

Questions from the Subcommittee

My responses to the Subcommittee's questions are based primarily on information provided in three Board publications: *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*, issued in October 2009; *Experience Gained From Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries*, issued in April 2011; and *Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Waste*, issued in June 2011. Here I should call

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attention to the fact that the Board as currently constituted was not involved in the development of any of the reports. I will, therefore, update or supplement the report material from my own experience and from Board analyses or evaluations that are currently underway. As I mentioned earlier, the *Survey Report* will be updated, as necessary, to reflect current developments and changing circumstances in international programs.

I will address the questions in the order they were presented by the Subcommittee:

Question One: What do international and U.S. experiences tell us about consent-based siting?

In general, most national programs for siting a deep-mined geologic repository for SNF and HLW are attempting to use some form of consent-based siting process – for very good reasons, but with varying degrees of success. As has been learned from siting efforts in this country, not having the consent of the affected units of government at the potential host site, including the state, community, and Native American Tribe(s) can create problems that delay or stop the process altogether. But using a consent-based process does not guarantee that a repository will be successfully sited, as was most recently demonstrated by the experience in the United Kingdom that I will discuss in more detail later in my testimony.

In the last 40 years, roughly two-dozen efforts to identify or create processes for identifying potential repository sites have been initiated in the United States and other countries. Of those, only three have identified a potentially suitable site *and* are still on track. In no case has a license been issued to construct a deep-mined geologic repository for high-activity radioactive waste by the responsible regulatory authority.

I will summarize briefly the experiences of some of the countries that are attempting to site a deep-mined geologic repository for the disposal of SNF and HLW.

Sweden – Perhaps the most encouraging example of the efficacy of a consent-based siting process is the approach used in Sweden. After an earlier siting effort failed, in 1992, the Swedish Nuclear Fuel and Waste Management Company (SKB) invited approximately a dozen Swedish communities to participate in a process meant to explore their interest in hosting a repository for high-activity waste. At the end of a very extensive engagement process, two municipalities, Osthammar and Oskarshamn, signaled that they were prepared to host such a facility. SKB ultimately selected Osthammar.

France – Early on, two French communities, one with a clay site and one with a site in granite, stepped forward to host an underground research laboratory with the understanding that, if the geologies proved suitable, a repository might be located there. However, the granite formation proved technically unsuitable for repository development and no other volunteer community with a granite site was found. In 2006, Parliament designated an area near Bure in Meuse/Haute Marne as the repository site in clay. It is interesting to note, however, that when the National Radioactive Waste Management Agency (ANDRA), called for volunteers to host a separate repository for long-lived, intermediate-level waste, several communities in the same province as Bure declined.

United Kingdom – In 2006, the United Kingdom approved a new approach for developing a repository, which included inviting willing communities to express interest in hosting such a facility. Several borough and county councils near the Sellafield reprocessing site in West Cumbria formed a partnership to investigate the possibility of participating. In January 2013, the local authorities voted on whether to proceed to the next stage in the process. Although the Borough Councils in Copeland and Allerdale voted overwhelmingly to move forward, the Cumbria County Council rejected the proposal. Immediately after the County Council vote, the

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UK Department of Energy and Climate Change announced that it was halting all activity related to siting a repository in Cumbria.

Canada – A promising national consent-based initiative is unfolding in Canada. Adopting a deliberate and careful approach to understanding the views of Canadians, especially Canada's aboriginal people, the Nuclear Waste Management Organization (NWMO) put forward a plan for adaptive management of Canada's high-activity waste. NWMO is working with twenty-one communities that have expressed interest in learning more about the implications of hosting a deep-mined geologic repository.

Japan – In sharp contrast to the Canadian experience, more than a decade ago, Japan's Nuclear Waste Management Organization (NUMO), called for volunteer communities to participate in a stepwise repository-siting process. Although the mayor of one southern Japanese town accepted NUMO's offer, opposition quickly developed at both the local and prefecture levels. The mayor was recalled, and no other community has come forward since. After the damage caused to the Fukushima-Daiichi reactors by last year's earthquake and tsunami, the prospects for volunteers coming forward now appear to be even slimmer.

Switzerland – In Switzerland, the typical siting approach of starting with a call for volunteers has been reversed. The government authority first identified five regions where the Opalinus clay might be suitable for locating a repository. Now, in the plan's second phase, discussions are under way with communities in the regions to determine if any of them are prepared to host a repository. Ultimately, the Swiss Federal Government will decide where a repository will be sited, but that decision could be overturned by a national referendum.

Germany – In the 1970s, the State of Lower Saxony invited the German federal government to develop a repository in salt near the community of Gorleben. That expression of

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interest aroused considerable controversy nationally. Although the site is still under consideration, 35 years later there is no decision about whether or not to proceed with development of a repository there.

United States – In the U.S., the experience of *the Nuclear Waste Negotiator* may be especially relevant because that effort was truly consent-based. The Negotiator was given authority to search for a voluntary host for a storage facility or a permanent repository site and to negotiate a benefits package with any acceptable incentives. Approval by act of Congress would be required to complete the process. Some local communities expressed interest, but the states in which they were located prevented them from pursuing an agreement with the negotiator. Some Native American Tribes sought agreements, but in 1995, funding for the Office of the Negotiator was eliminated by Congress. It is not clear what factors would lead to a different outcome if that effort were reinitiated today.

The experience of the *Waste Isolation Pilot Plant* (WIPP) also is instructive when looking at consent-based programs for siting nuclear repositories. This is a subject I know about from personal experience: A committee of the NAS National Research Council continuously reviewed the WIPP project for several decades, and I was a member of that committee from 1984 to 1996. During that time, I lived in New Mexico, having become a member of the faculty at the University of New Mexico in 1974. As a result, I had a front row seat from which to observe the evolution of the WIPP project.

The WIPP facility in New Mexico is the only operating deep-mined geologic repository for radioactive waste in the world. The transuranic-contaminated (TRU) radioactive waste disposed of at WIPP is very different from the SNF and HLW that was intended for disposal in a repository at Yucca Mountain. The regulator also was different; EPA regulated the WIPP site,

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while the NRC is responsible for Yucca Mountain licensing. The siting experience was different, as well. In a 1957 report, the NAS identified salt formations as the “most promising” medium for the long-term management of HLW. In the 1970s, municipal leaders in Carlsbad, New Mexico, who were facing a decline in the local potash industry, advocated strongly for a site near their town to be considered as the location of a repository for TRU waste. Congress authorized the development of WIPP and directed DOE to enter into a “consultation and cooperation” agreement with the State of New Mexico. The State created the Environmental Evaluation Group (EEG) to advise on health and safety effects of the proposed repository and to ensure that technical issues were rigorously addressed. Despite its inability to enforce its recommendations, the EEG did prompt changes in DOE’s plans. Nonetheless, DOE’s decision to proceed with WIPP was challenged by the state and non-government organizations until the passage of the WIPP Land Withdrawal Act in 1992. The State of New Mexico’s cooperation has depended, at least until now, on an agreement that precludes the disposal of HLW and SNF at the facility or near the site, and the Land Withdrawal Act includes a provision that limits WIPP’s mission to the disposal of TRU waste. However, Carlsbad’s leaders have expressed considerable interest in expanding the facility’s mission.

The important observations to be made about these national programs may be that what characterizes them most is their variety and that there is no consistent formula for success. In some cases, efforts to identify candidate sites have focused from the beginning on specific host-rock formations dictated by a country’s geology or land-use patterns, by a view that particular host-rock formations possess distinctive advantages, or a combination of these factors. In other cases, countries use qualifying and disqualifying conditions to determine the suitability of a site. In addition, a country can evaluate sites serially or in parallel.

Since the early 1990s, nations other than the United States increasingly have developed approaches that empower local jurisdictions. How power is distributed among the affected units of government can be very consequential, as demonstrated by the situations in Japan, Germany, Switzerland, the United Kingdom, and the United States. Experiences in the United States and other nations also suggest that communities already hosting nuclear facilities and communities where benefits might make a significant economic or social difference may be especially receptive to being considered as a candidate repository site.

An important lesson that can be taken from the experiences of national programs, and in particular from the experience of the WIPP facility in the U.S., is the importance of ongoing independent technical review and evaluation. It is not clear whether without such oversight a consent-based process could be successful in this country, regardless of whether it was conducted by DOE or by another organization inside or outside the government.

Question Two: *What can we learn from Yucca Mountain, technically and otherwise?*

Given the Board's technical and scientific mandate, I will focus first on some of the technical and scientific lessons that can be taken from the Board's June 2011 "Technical Advancements and Issues" Report, which looked at the technical and scientific experiences of the Yucca Mountain Program (YMP) and other programs world-wide:

- A variety of geologies can be viable candidates for a repository, including intrusive or extrusive igneous rocks (e.g., granite and tuff), metamorphic (e.g., basement rocks of the Canadian Shield), and sedimentary rocks (e.g., salt and clay).
- There may be alternatives to the "one-size fits all" approach used by the Yucca Mountain Program for the disposal of SNF and HLW.

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- Expect surprises in any underground site investigation.
- Engineered barriers can delay reliance on the waste-isolation capabilities of the natural system.
- In general, in the presence of water, the higher the temperature, the more rapid will be the degradation (corrosion) of the waste package.
- When compared with oxidizing environments, emplacement of high-activity waste in reducing environments has important advantages that enhance long-term isolation of the waste from the environment.
- Natural analogs were invaluable for evaluating the Yucca Mountain site. Natural analogs should be identified and studied early as part of the site-characterization process.

Some non-technical lessons from the report include:

- A deep-mined geologic repository for the disposal of SNF and HLW is needed under all realistically foreseeable circumstances.
- An implementing waste management organization that has continuity of funding, management, and personnel is very important.
- Undue delay makes it difficult to implement a concept of waste management that depends on institutional stability.
- Implementing a permanent repository could take decades.

I would add that, as mentioned earlier, successfully siting a repository for disposal of SNF and HLW is difficult or impossible without the consent of the affected units of government

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that will be hosting the facility. To be acceptable to the affected units of government, the technical suitability of the site also must be established.

Question Three: *What is the current thinking and consensus around preferable options for waste disposal and siting?*

Repository Options: The international consensus, confirmed by the Blue Ribbon Commission on America's Nuclear Future (BRC) and many previous reports from national and international organizations, is that disposal in a deep-mined geologic repository is a workable and safe solution for SNF and HLW. Regardless of the fuel cycle selected, some fraction of the nuclear waste generated will require geologic disposal.

There are other options for disposal of SNF and HLW in addition to deep-mined geologic disposal, including deep borehole disposal of SNF, HLW, or "orphaned," special waste streams. In its final report, the BRC recommended that DOE should undertake studies on the use of deep borehole disposal for some forms of waste that essentially have no potential for reuse.

The Board is a preparing a fact sheet and letter on this subject, and its analysis so far indicates that deep borehole disposal, if it proved to be physically feasible, might have some advantages for disposing of SNF and HLW that has little potential for reuse. However, vitrified waste as it currently exists in metal canisters filled with glass may be too large for the boreholes envisioned for deep borehole disposal. Also, commercially generated SNF and DOE-owned SNF is stored in canisters with a wide-range of sizes and shapes, so repackaging into smaller canisters also would be required for that waste. There are other daunting challenges associated with deep borehole disposal related to developing new drilling technologies, the emplacement and effective sealing of waste packages at great depth, and the need to address the potential retrieval of the emplaced waste.

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Because of the present uncertainties associated with deep-borehole technologies, the Board recommends that deep borehole research and development not distract the U.S. program from vigorously pursuing the siting and characterization of a deep-mined geologic repository.

Repository-Siting - A top legislative priority should be to establish a clear path for a consent-based repository-siting process. The Board presently is developing its own recommendations on this topic. Already, from my personal perspective, a few basic requirements are clear:

1. There must be a set of technical criteria by which sites are evaluated.
2. There should be a clear statement of how all affected units of government (e.g., local community, Native American Tribe, and state) will be engaged in the consent-based process.
3. There should be a clearly understood process by which the affected units of government can opt out of the siting process.
4. There should be a clear understanding of the time after which the affected units of government can no longer withdraw their consent.

DOE Preservation of Yucca Mountain Data and Documents

Finally, I want to update the Subcommittee on an upcoming Board report on DOE's efforts to preserve Yucca Mountain data, documents, and other materials. The report is both appropriate to the subject of the hearing and is being drafted by the Board as the final phase of a review activity that was prompted, in large part, by direction from the Appropriations Committee.

For almost 30 years, DOE studied the Yucca Mountain site. In 2010, when the Yucca Mountain program was shut down, responsibility for archiving and preserving Yucca Mountain scientific and engineering information was transferred to the DOE Office of Legacy Management (LM).

The Board began evaluating DOE activities related to archiving and preserving Yucca Mountain data and information in 2010, as part of its ongoing technical and scientific review. The following year, the Report accompanying the Fiscal Year 2012 Energy and Water Development Appropriations bill directed the Board to "give support to" DOE as it archived and preserved scientific data, documents, and other materials from the YMP.

In accordance with its mandate and consistent with the Committee's direction, the Board has conducted a review of DOE's data-preservation activities, including a limited number of retrieval spot checks, and will soon send its report to Congress and the Secretary. The report is currently being finalized; the following is an "unofficial" overview of the Board's findings:

- Yucca Mountain documents have been preserved and can be accessed and retrieved.
- With significant time and effort, LM personnel can search and retrieve relevant e-mail records.
- LM does not have the capability to load and execute most of the analytical software used on the YMP.
- Some boxes of YMP records being stored by LM contain physical objects, but the inventories of the contents vary in how detailed they are. Consequently, it is unclear what measures might be needed to preserve them or to create searchable databases for the objects.
- LM has used approved NARA schedules to identify what YMP records should be preserved permanently and what records should be preserved temporarily.

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- The general public can access written records held by LM, but only through a Freedom of Information Act request.

The Board plans to issue its report in the near future.

Summary

To summarize some key points from my testimony, I would observe that not using a consent-based approach for repository siting can slow the process or lead to delay or failure, but using a consent-based process does not guarantee that a repository will be successfully sited. Programs in other countries are using a variety of consent-based approaches, with mixed results. Deep-mined geologic disposal remains the approach that is being pursued by most of the countries with nuclear waste programs, worldwide, and a deep geologic repository will be needed regardless of the fuel cycle option selected. The only operating deep-mined geologic repository in the world for disposal of radioactive waste is the WIPP facility in New Mexico, and important lessons can be taken from the development of that facility. Finally, ongoing, independent technical oversight of the activities undertaken by the implementer of a consent-based repository-siting program is crucial, regardless of whether the implementing entity is a government agency, a non-governmental organization, or a federal corporation.

Thank you very much. I will be happy to respond to questions.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

June 7, 2013

The Honorable Ron Wyden
Chairman
Committee on Energy and Natural Resources
United State Senate
Washington, DC 20510

The Honorable Lisa Murkowski
Ranking Minority Member
Committee on Energy and Natural Resources
United States Senate
Washington, DC 20510

Dear Chairman Wyden and Senator Murkowski:

The U.S. Nuclear Waste Technical Review Board was created by Congress in the 1987 amendments to the Nuclear Waste Policy Act (NWPA) to evaluate the technical and scientific validity of Department of Energy activities related to implementing the NWPA and to provide independent technical and scientific findings, conclusions, and recommendations on the management and disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) to Congress and the U.S. Secretary of Energy.

Consistent with the Board's mandate, the Board submits the enclosed comments, recommendations, and observations that are relevant to provisions of the discussion draft on Comprehensive Nuclear Waste Legislation released by the Committee on Energy and Natural Resources on April 25, 2013. The Board's comments are largely based on information from Board reports on international experience and are focused on provisions of the proposed legislation that will affect or be affected by technical issues.

The Board believes that the Committee should be commended for taking action on moving forward with a proposed approach for permanently disposing of SNF and HLW. The Board hopes the Committee will consider the Board a technical resource and will feel free to call on the Board to address questions related to the enclosed comments or to any other technical matter relating to SNF and HLW management and disposal.

Sincerely,

{Signed by}

Rodney C. Ewing
Chairman

Enclosure

U.S. Nuclear Waste Technical Review Board
Comments on the Senate Committee on Energy and Natural Resources
Discussion Draft of Comprehensive Nuclear Waste Legislation
Released by the Committee on April 25, 2013

The U.S. Nuclear Waste Technical Review Board was created by Congress to evaluate the technical and scientific validity of Department of Energy (DOE) activities related to managing and disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) and to provide independent technical and scientific findings, conclusions, and recommendations on these issues to Congress and the U.S. Secretary of Energy. Consistent with the Board's mandate, the Board submits the following comments on the discussion draft on Comprehensive Nuclear Waste Legislation released by the Committee on Energy and Natural Resources on April 25, 2013. The Board's comments are largely based on information from Board reports on international experience with SNF and HLW management and disposal and are focused on provisions of the proposed legislation that will affect or be affected by technical issues.

Consent-Based Process

- "Consent-based" is not defined in the discussion draft. International experience supports the need for an explicit description of the consent-based process, including the conditions under which the implementer, a state, localities, or Native American Tribes (if applicable) may withdraw from the process to site and/or evaluate a site for a proposed nuclear waste facility. The consent-based process should clearly define the division of authority, roles, and responsibilities among the various levels of government. The consent-based process also should be tied to a logical sequence of scientific and technical determinations of the suitability of the site.
- International experience demonstrates the value of early engagement and partnership with affected parties, including states, communities, and Tribes and keeping them regularly informed throughout the process. To enhance understanding and ensure informed consent, along with relevant general information, technical information on the implications of hosting a nuclear facility should be widely disseminated among and discussed with the affected units of government.
- Based on international experience, in order to ensure informed consent, an agreement that includes terms and conditions negotiated among the parties should be executed *early* in the siting process.

Site Characterization

- Except in the definitions section of the discussion draft, the components and requirements of a site-characterization program for determining final site suitability before licensing are not clearly established in the proposed legislation. Additional detail is needed along the lines of the guidance provided in Section 113 of the Nuclear Waste Policy Act on the conduct of a site-characterization program. Understanding what a site-characterization program entails will be important information for potential voluntary hosts of nuclear waste facilities.

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- The proposed legislation provides that at least one site be characterized as a repository and at least one site be characterized as a storage facility. Based on international experience, consideration should be given to characterizing multiple candidate sites in parallel as recommended by the Interagency Review Group in 1979 and subsequently by the Office of Technology Assessment.

Safety Case and Regulatory Standard

- Based on international experience, the safety case for disposing of HLW and SNF should be peer-reviewed and should include a synthesis of evidence, analyses, and arguments that quantify and substantiate the basis for a determination that a repository will be safe after it is closed. A well-developed safety case would make clear what sites might be suitable and what sites might be unacceptable, including to the extent possible, the health and safety requirements that must be met for the nuclear waste facility to be licensed.
- A process for establishing a health and safety standard is not included in the legislation. The Board notes that the Blue Ribbon Commission on America's Nuclear Future recommended that "The standard and supporting regulatory requirements to license a facility should be generic—that is, applicable to all potential sites" and that "Safety and other performance standards and regulations should be finalized prior to the site-selection process."

Implementing Organization

- Based on international experience, organizations that have as their sole purpose the long-term management of radioactive waste are more effective than multipurpose organizations; the particular form of the single-purpose organization seems less important.
- Because investigating and evaluating sites to determine their suitability as the location of a nuclear waste facility are inherently technical and scientific activities, individuals with technical and scientific expertise should be part of the management and oversight structure of the new organization. For example, a Chief Scientist should be designated to oversee all the activities that support the site-evaluation program, including site-characterization and research and development activities (e.g., analyses of waste form durability and waste-package corrosion). The membership of the Oversight Board also should be broadened to include additional technical and scientific expertise. Representation from academia, industry, public interest groups, state/local groups, and/or international nuclear waste programs should be considered. The Board strongly supports language in the discussion draft, which continues the Board's ongoing independent evaluation of the technical and scientific validity of activities undertaken by the Administrator, and believes that the Board should continue to review activities that are retained by the Secretary related to the disposal and transportation to a repository of DOE-owned SNF and HLW. The Board also could make a valuable contribution as peer reviewer of the safety case developed by the Administrator.
- Especially if a single geologic repository is the disposal site for both SNF and HLW, activities related to disposing of commercial SNF should be fully integrated with efforts to dispose of DOE-owned SNF and HLW. Currently, one organization—the DOE—has responsibility for implementing a program for managing and disposing of these wastes. If, as a result of legislative changes, activities

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such as research and development of the HLW waste form or packaging of HLW are managed by separate organizations, the roles and responsibilities of the organizations should be more fully defined in the legislation, and additional detail should be added on how the organizations will interact to ensure effective integration.

Transportation of Defense Waste

- Section 308 of the discussion draft should provide for transportation of defense waste from a DOE site to a storage facility or disposal site.

Responses to Questions 4 and 5 from the Committee List:

- <u>Question 4</u>: *To what extent should the siting and consensus approval process for spent fuel storage facilities differ from that for the repository? Should the Administrator be required to conduct sufficient site-specific research (referred to as "characterization" in the bill) on candidate storage sites to determine if they are suitable for storing nuclear waste or only on candidate repository sites to determine if they are suitable for geologic disposal of nuclear waste? Should the Administrator be required to hold public hearings both before and after site characterization (as required by current law in the case of the Yucca Mountain site) or only before site characterization?*

  Answer: Yes. Given the preference for a co-located repository and storage facility cited in Sec. 304(d) (2), and the consent-based approach for determining sites that are eligible for review for hosting a nuclear waste facility, the Administrator should be required to conduct sufficient site-specific research on candidate storage sites to determine if they are suitable for storing *and* disposing of nuclear waste*, if* those sites also have been identified as potential sites for disposal.

- <u>Question 5</u>: *Should the siting process in section 304 of the draft bill be streamlined? If so, how?*

  Answer: The determination in the discussion draft of whether a site is scientifically and technically suitable for development as a repository or storage facility requires that sufficient site-characterization information has been developed, through the siting process and site-characterization processes, to support an application for a construction authorization. The proposed two-stage decision-making process, which requires (1) evaluation of existing information for a decision on whether a site is suitable for characterization as a consolidated storage facility or a repository and (2) using the results of a full-scale site-characterization program to make a final determination of site suitability before submitting a license application, would appear to be appropriate for developing sufficient information for decision-making. It also would provide two distinct opportunities for affected parties to provide input at decision points in the siting process. Ongoing input from affected and interested parties throughout the process would support the consent-based process and the development of a sound scientific basis for decision-making.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

September 16, 2013

The Honorable Rodney P. Frelinghuysen
Chairman
Subcommittee on Energy and Water Development
Committee on Appropriations
2362B RHOB
U.S. House of Representatives
Washington, DC 20515

Dear Chairman Frelinghuysen:

I want to thank you again for the opportunity to testify before the Subcommittee on Energy and Water Development on April 11, 2013. One of the questions I was asked to address at the hearing is "What do international and U.S. experiences tell us about consent-based siting?" In light of recent developments, with this letter I provide additional comments that I believe are relevant to the question posed by the Subcommittee on the experience gained through Board interactions with disposal programs for high-level radioactive waste (HLW) and spent nuclear fuel (SNF) in Sweden and France.*

In February 2010, the Administration announced, among other things, that it intended to disband the Office of Civilian Radioactive Waste Management (OCRWM) and transfer its responsibilities to other units within the Department of Energy (DOE). On October 1, 2010, OCRWM ceased to exist. The Blue Ribbon Commission on America's Nuclear Future (BRC) recommended that a new single-purpose organization be created outside of DOE to replace OCRWM. But, regardless of whether a deep-mined geologic repository for HLW and SNF is developed at Yucca Mountain or legislation is passed that changes the direction of the country's approach to nuclear waste management, a new implementing organization for the repository program will likely have to be established.

What kind of implementing organization should be created in this case is a matter for decision-makers in Congress and the Administration to determine; only policy-makers can balance the competing objectives that are inevitably associated with the creation of a new institutional form. Importantly, both the BRC's final report and the Administration's "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste"

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* Copies of this letter also will be forwarded to the Senate Committee on Energy and Natural Resources as follow-up to previous Board comments on the Committee's nuclear waste legislation and to the Senate Committee on Public Works, Subcommittee on Clean Air and Nuclear Safety, to follow up on comments made by Board Senior Professional Staff member, Daniel Metlay, at a hearing held by the Subcommittee in July 2012.

recognize that institutional issues and choices can affect technical activities.[1] That link between institutional design and scientific and engineering execution prompts this letter.

Since its establishment, the Board has followed closely the work of other national waste management programs to learn how they have addressed the same set of challenges and issues that the program in the United States necessarily must confront. Over the years, delegations from the Board have visited Sweden and France and met with personnel from each country's implementing organization (SKB in Sweden and ANDRA in France) as well as with other parties such as radioactive waste producers, regulators, overseers, and leaders of communities that are potential hosts to a deep-mined geologic repository. What follows are observations derived, not only from those interactions, but also from Board evaluations and reports.

- Successful waste-management programs are being implemented by private, hybrid, and public organizations.
- Successful implementing organizations emphasize a single-minded commitment to long-term safety, including, but not limited to, complying with the requirements of the regulatory authorities.
- Successful implementing organizations place a high value on sustaining public trust and confidence and accord a high priority on doing so in their everyday choices.
- Successful implementing organizations establish processes by which they respond to new information and circumstances.
- Successful implementing organizations appreciate that disposing of HLW and SNF presents operational challenges and, therefore, develop prototypes and techniques to address ahead of time those challenges.

The basis for these observations is elaborated upon in the remainder of this letter.

How an organization functions is more important than its structure

Debates over whether the implementer of a high-level radioactive waste management program should be a public agency, a public-private hybrid, or a private company cannot escape the fact that all of those institutional forms have been effective in at least one country. Which approach is best for the United States will continue to be contested because claims are based largely on impressionistic evidence, "expert" judgments, and anecdotes—not on systematic analyses.

However, the weight of evidence and experience supports the proposition that, all other things being equal, an implementer focused on a single purpose is more effective than one that has multiple objectives. In the 1982 Nuclear Waste Policy Act (NWPA), Congress established OCRWM as a single-purpose office in DOE with the aim of elevating the importance of the disposal program within the multipurpose agency. However, embedding OCRWM in DOE only

[1] Among other things, the BRC expected that its recommended new organization would be able to "achieve and sustain high standards of technical" performance. BRC, *Report to the Secretary*, (Washington, 2013) p. 62. Department of Energy, "Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste," (Washington, 2013).

partially reversed the low priority previously accorded to waste management; OCRWM had to compete with other DOE units for resources and attention, and OCRWM could not escape criticisms directed at the parent agency. The Board and many others have noted that this situation complicated OCRWM's technical efforts.

Almost universally, other nations have taken a different tack.[2] By the mid-1970s, Sweden and Finland had created single-purpose implementing organizations. The French Parliament in 1991 completely separated ANDRA from the larger Commissariat à l'énergie atomique (CEA). Since then, more than a half-dozen countries, including Belgium, Canada, Hungary, Japan, Spain, and Switzerland, have opted to give to single-purpose organizations the responsibility for the long-term management of HLW and SNF.[3]

Yet, as implicitly recognized in a recent RAND study[4] commissioned by DOE's Office of Nuclear Energy, what counts most is not organizational anatomy (how the pieces are structured and tied together) but organizational physiology (how the pieces behave, interact, and function).[5] From the Board's perspective, the two key "physiological" elements are (1) the impact of organizational culture on technical work and (2) how the organization responsible for implementing a nation's waste management program addresses critical scientific and engineering issues. Because both the Swedish and French programs are so advanced, examining how SKB and ANDRA function may suggest important lessons for any new implementing organization.

Organizational culture drives organizational behavior

SKB leaders have remarked on a number of occasions and SKB managers have repeatedly maintained that the organization's mission could be summarized simply: (1) demonstrate long-term safety and (2) sustain public acceptance. ANDRA's personnel have not characterized their mission as succinctly but, like the Swedes, they have made clear that other objectives, such as schedule and cost, are subordinated to safety and acceptance.

The language used by the implementers in both nations differs substantially from comparable expressions used by OCRWM in the past. The emphasis in Sweden and France is on advancing a clear and persuasive safety case and then carrying out a focused research *and* development program designed to address key scientific and engineering questions. Although both implementers are unavoidably concerned about obtaining permission from the authorities to construct a deep-mined geologic repository, only rarely do they describe their work as directed toward satisfying regulatory requirements. Obtaining fundamental scientific understanding and

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[2] The implementer in the United Kingdom (NDA) is not a single-purpose organization; but plans have been announced to split off a separate single-purpose unit to develop a deep-mined geologic repository. The new implementing organization that is expected to be created in Germany is likely to have a single purpose.

[3] It may be coincidental, but three of the most vigorous nuclear waste management programs are run by dedicated utility-owned organizations (Canada, Finland, and Sweden).

[4] T. LaTourrette et al., *Managing Spent Nuclear Fuel: Strategy Alternatives and Policy Implications*, (RAND: Santa Monica, CA, 2013).

[5] There does not appear to a strong connection between organizational anatomy and physiology.

demonstrating engineering practicability, not compliance, seem to be the predominant motivations.

This single-minded focus on long-term safety lends credence to three messages that these implementers convey to the general public as well as to interested and affected parties. First, the long-term management of nuclear waste is a pressing societal and environmental problem that has to be addressed regardless of the long-term prospects for nuclear energy production. Community leaders from both Östhammar and Oskarshamn, the Swedish municipalities ultimately evaluated as potential repository sites, explicitly mentioned that their engagement with SKB is influenced by a desire to advance a larger national interest.

Second, considerable attention is being paid to framing nuclear waste management as an issue strongly affecting intergenerational equity. In Sweden, for example, the Board's sister agency, now called the National Council for Nuclear Waste, sponsored a public seminar on ethics and nuclear waste management in 1987. The following year, the Swedish authorities published a report that focused on the question of intergenerational equity.[6] It appears that SKB and ANDRA officials have internalized this concern.

Third, both implementers, but especially the French, recognize that the process for developing a deep-mined geologic repository must be stepwise and adaptive.[7] ANDRA published a book-length study that explores both the technical and institutional matters that need to be considered in implementing such a process, which must repeatedly assess whether the course being undertaken should be continued, revised, or abandoned.[8]

For SKB and ANDRA, public acceptance requires a dynamic and sustained effort to engage interested and affected parties. Each implementer has established a strong and long-standing local presence in the communities that might host a repository.[9] Although education is an important component of their engagement activities, listening respectfully, responding to all questions, soliciting the residents' opinions and values, and adopting at least some suggestions

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[6] National Swedish Board of Spent Fuel, *Ethical Aspects of Nuclear Waste,* SKN Report 29, (Stockholm, 1988). See also, Special Advisor for Nuclear Waste Disposal, *Responsibility, Equity, and Credibility—Ethical Dilemmas Relating to Nuclear Waste*, Ministry of the Environment, (Stockholm, 2001).

[7] The case for adopting such a process has been set forth best by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, *Stepwise Approach to Decision Making for Long-Term Radioactive Waste Management: Experience, Issues, and Guiding Principles*, (Paris, 2004). See also, National Research Council, *One Step at a Time*, (National Academy of Sciences: Washington, 2003). The BRC also makes this point. The Canadian program is probably the gold standard when it comes to implementing a stepwise, adaptive repository development process.

[8] L. Aparicio, *Making Nuclear Waste Governable: Deep Underground Disposal and the Challenge of Reversibility*, (Springer: Paris, 2010). Although reversibility may be easily achievable at the first stages of repository development, it is likely to be harder to accomplish at later stages. Important challenges having to do with detecting the need for and implementing adjustments will have to be addressed.

[9] In the case of Sweden, the nuclear-utility owners of SKB have a long and positive history operating power plants in both Östhammar and Oskarshamn.

are at the core of their interactions. Among the many dividends derived from these engagement efforts is that a deep reservoir of trust appears, by all indications, to have been created.[10] This trust means that technical issues can be debated without rancor and that the implementer is given the benefit of doubt as it proceeds to plan for the repository's development.

Both implementers realize that trust needs to be assiduously built and constantly maintained through openness, engagement, and transparency.[11] Unlike OCRWM, the Swedish and French implementers seem to have learned from experience and have taken to heart what are, in effect, the major findings and recommendations put together by task forces commissioned by three different Secretaries of Energy.[12] In particular, the Board has been struck by how often SKB and ANDRA personnel, without being prompted, offer observations that make the following general points:

- Trust must be gained over a long period but it can be lost almost instantaneously.
- Public trust and confidence is not a luxury. The implementer has an obligation to earn it but also a compelling need to do so.
- Lack of public trust and confidence is an obstacle to programmatic progress.
- Efforts to restore and sustain public trust and confidence cannot simply be appended to on-going activities. Senior officials and managers must recognize that most organizational choices have consequences for institutional trustworthiness. Leaders need to seriously weigh those consequences when key decisions are made.

These observations do not appear to be empty platitudes. Both implementers make readily available technical information as well as internal emails. SKB executives reward individuals with proven track-records for building public trust and confidence, and they seem to understand that, for the public, a feeling of safety is based on trust in politicians, industry, regulators, and the process. ANDRA officials have decided to defer to local views about the placement of the proposed repository's surface facilities *because* such deference would enhance trust. And in Sweden, the implementer had established such a reservoir of trust that no one seriously questioned the technical rationale that underlay the choice of the Östhammar repository site over the apparent front-runner, Oskarshamn.[13]

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[10] That the regulatory authorities are apparently well-trusted probably affects the implementers' attitudes about creating and maintaining public trust and confidence.

[11] The actions of SKB and ANDRA from the early 1990s on stand in sharp contrast with their earlier actions to identify potential sites for a repository. Then, both implementers proceeded without engaging or gaining the trust of the communities involved. Moreover, the two implementers are not necessarily trusted by all interested and affected parties, including those who oppose the repository projects. Rather, the Board has been struck by how widespread the trust is and how central its maintenance was for the implementers.

[12] Secretary of Energy Advisory Board (SEAB), *Earning Public Trust and Confidence: Requisites for Managing Radioactive Waste*, (Washington, 1994); SEAB II, *Responsible Openness: An Imperative for the Department of Energy*, (Washington, 1997); SEAB III, *Relations between DOE Facilities and their Host Communities: A Pilot Review*, (Washington, 2000).

[13] SKB, *Site selection—siting a final repository for spent nuclear fuel*, R-11-07, (Stockholm, 2011).

In sum, due in large part to their own approaches and efforts to build trust, SKB and ANDRA operate within a relatively stable political environment. Consequently, the technical cores of those organizations appear to be mostly walled off from disruptive external pressures. Work can be directed at well-specified scientific and engineering problems, and that work is carried out in an atmosphere that encourages candid exchanges, not only with the international technical community, but also with a wide range of individuals and organizations at home.

How an organization addresses technical issues is important for repository development

From its interactions with the two implementers, the Board has come to appreciate what "ingredients" might be necessary (although probably not sufficient) to carry out a technically sound repository development process. Three appear worthy of note: (1) steady availability of resources; (2) adaptability; and (3) attention to the details of deployment.

One consequence of operating within a relatively stable political environment is that there is broadly based support for work to address long-term safety questions. This continuity is crucial because establishing the case for a repository is a decades-long and sometimes tedious process. For example, the Swedish safety case relies on the integrity of a bentonite barrier that surrounds the waste packages, minimizing water flow past them and absorbing radionuclides that might be released. The French safety case relies on the very slow movement of water through argillite (clay-rich rock) formations. Demonstrating the capabilities of these barriers requires investigations that have to be conducted over substantial periods of time. Experience in Sweden and France indicates that long-term, multi-year, assured budgets provided a number of benefits, including more efficient planning and implementation of an integrated research program and the retention of key personnel.

A stepwise and adaptive repository development process is premised on the likelihood that new technical information or shifts in policy might demand mid-course modifications. Both implementers have demonstrated a capacity—albeit sometimes imperfectly—to make adjustments in a technically credible and publicly transparent manner.

Another element of the Swedish safety case is the assertion that waste canisters fabricated from elemental copper will not corrode in the anoxic groundwater to which they will be exposed. That proposition appeared for many years to be supported by fundamental principles of thermodynamics. Experiments conducted at the Swedish Royal Institute of Technology (KTH), however, called that claim into question. The regulatory authorities expressed considerable interest in this new information.[14] SKB's response has been two-fold. It supported a pair of independent investigations to see if the KTH results could be replicated and sponsored the creation of a formal "reference group" of interested and affected parties to monitor the progress

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[14] For an independent review of the copper corrosion issue, see National Council for Nuclear Waste, *Mechanisms for Copper Corrosion in Aqueous Environments*, Report 2009:4e, (Stockholm, 2009). Two former Board members were key participants in the National Council's scientific workshop devoted to this issue.

of those studies.[15] SKB also performed additional safety assessments to determine the consequences for public health *if* the KTH findings were substantiated.

The French implementer also faced challenges to its approach. A public debate held in 2005 revealed a strong preference for a disposal concept that permits reversibility for perhaps as much as 100 years. That public demand was incorporated into legislation the following year. Since then, ANDRA has been working on alternative repository designs that would satisfy the law's requirements. These have been the subject of technical conferences and have been opened up to international peer review.[16] ANDRA will need to choose one design when it submits a license application to the regulatory authorities, an event projected to occur sometime in 2015.

SKB and ANDRA understand better than OCRWM did that their responsibilities extend beyond articulating a safety case and supporting it before the public and the regulators. Both SKB and ANDRA are looking ahead to determine what it will take to operate a deep-mined geologic repository in a manner that will not endanger the reservoir of trust that the organizations have built up over the years. For that reason, both implementers constructed underground research laboratories in rock formations and depths virtually identical to those where a repository might be developed. They also concluded that it is essential to develop full-scale prototypes of critical systems before a license application was submitted and to test the performance of those systems *in situ*. Neither SKB nor ANDRA are prepared to claim that the technologies required could be taken off the shelf or would somehow become available at a later stage.[17]

One of the greatest challenges that all implementers will face is the emplacement of waste packages and engineered barrier systems (EBS) within the host rock. This operation, which typically will have to be performed in a high-radiation, low-visibility environment, will need to be executed remotely. Should the EBS be misaligned or incorrectly emplaced, the long-term safety of the repository could be degraded and, perhaps, jeopardized.

The Swedish disposal concept specifies that, before a waste package is lowered into the host rock, highly compacted bentonite blocks and rings have to be placed into the vertical disposition holes. The tolerances are extraordinarily tight. To determine whether the emplacement requirements could be met, SKB constructed prototype machines for installing the bentonite and for depositing the waste package. These systems have been repeatedly tested (in a non-radiological but underground environment) using fully automated navigation and positioning systems.[18]

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[15] The role of the reference group is to keep the interested and affected parties and the public fully and currently informed about the progress of the replication experiments and to allow its members to suggest modifications to the planned experiments.

[16] See, for example, Nuclear Energy Agency, *Reversibility and Retrievability in Planning for Geologic Disposal of Radioactive Waste*, NEA 6993, (Paris, 2012).

[17] The Board has commented on this issue in the past. See, for example, its *Report to the U.S. Congress and the Secretary of Energy: January 1, 2005 to February 28, 2006*, (Washington, 2006), pp. 18-20.

[18] SKB, *RD&D Programme 2010*, TR-10-63, (Stockholm, 2010).

In the French disposal concept, the EBS relies heavily on the waste package. However, because of the reversibility requirement enacted by Parliament, ANDRA has had to determine not only how to emplace the packages inside horizontal holes bored in the repository tunnels' walls but also how to extract the packages if so required. Several full-scale prototypes were developed, and preliminary tests have been conducted. Although final design requirements have not been set, ANDRA seems to have a basis for feeling confident that it can develop the technologies needed to implement the reversible emplacement of waste.

Some final thoughts on national differences

The Board well understands that recipes for developing a deep-mined geologic repository cannot be imported from abroad.[19] Some aspects of implementing a waste management program will strongly depend on a country's particular governance structure. For instance, how is power distributed between the central government on the one hand and regional/state/local governments on the other? Further, some aspects may likely depend on a country's political culture. For example, in both Sweden and France, individuals observed that having the "ground rules" for a consent-based siting process clearly specified in advance was an important condition for participating. In the United States, at least in the view of the BRC, these details are best left to individual negotiations.

National laws and political cultures seem to be less constraining when it comes to questions associated with organizational physiology. Certainly private and public organizations in the United States have track-records of focused problem-solving. Institutional trustworthiness is not unheard of in the United States. The Board believes that, while challenging, designing and operating a nuclear waste management organization that is both effective and merits public confidence is a practicable and attainable undertaking. The Board also believes that much can be learned from programs in other countries. We provide this summary of observations as a contribution to the development of any new implementing organization in the United States.

Sincerely yours,

{signed by}

Rodney C. Ewing
Chairman

cc: Ranking Member Marcy Kaptur

[19] U.S. Nuclear Waste Technical Review Board, *Experience Gained From Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries*, (Washington, 2011).

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Appendix E

Board Meetings—
January 1, 2013–December 31, 2015

Board Meetings—January 1, 2013–December 31, 2015

April 16, 2013	**Spring Board Meeting** Richland, Washington Waste Form and Disposal Issues
November 18-19, 2013	**Board Technical Workshop** Washington, DC Impacts of Dry-Storage Canister Designs on Future Handling, Storage, Transportation and Geologic Disposal of Spent Nuclear Fuel (SNF)
November 20, 2013	**Fall Board Meeting** Washington, DC DOE Research and Development Related to SNF and High-Level Radioactive Waste (HLW) Management
March 19, 2014	**Spring Board Meeting** Albuquerque, New Mexico U.S. Department of Energy R&D Related to Salt as a Geologic Medium for Disposal of SNF and HLW
August 6, 2014	**Summer Board Meeting** Idaho Falls, Idaho DOE Plans for the Packaging, Transportation, and Disposal of DOE SNF and HLW
October 29, 2014	**Fall Board Meeting** Atlanta, Georgia Vitrification of HLW, Storage of Vitrified HLW, and Processing of DOE SNF
June 24, 2015	**Summer Board Meeting** Golden, Colorado Transportation of SNF
October 20-21, 2015	**Board Workshop** Washington, DC International Technical Workshop on Deep Borehole Disposal of Radioactive Waste

Appendix F

Correspondence with the U.S. Department of Energy January 1, 2013–December 31, 2015

Correspondence with the U.S. Department of Energy January 1, 2013–December 31, 2015*

- *Letter from Dr. Peter Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy (DOE), to Dr. Rodney Ewing, Board Chairman; January 30, 2013*
  Subject: DOE response to December 11, 2012, Board letter.
- *Letter from Chairman Rodney C. Ewing to Mr. David Huizenga, DOE Office of Environmental Management; May 28, 2013*
  Subject: Board's reactions to DOE-EM presentations at April 2013 Board meeting.
- *Letter from Chairman Rodney C. Ewing to Dr. Peter Lyons, DOE Assistant Secretary for Nuclear Energy; May 28, 2013*
  Subject: Board comments on information presented at April 2013 Board meeting.
- *Letter from Chairman Rodney Ewing to Dr. Peter Lyons, DOE Assistant Secretary for Nuclear Energy; July 30, 2013*
  Subject: Deep borehole disposal.
- *Letter from Chairman Rodney Ewing to Dr. Peter Lyons, DOE Assistant Secretary for Nuclear Energy; January 29, 2014*
  Subject: Board comments on information presented by DOE-NE at November 2013 Board meeting.
- *Letter from Chairman Rodney Ewing to Dr. Peter Lyons and Mr. David Huizenga; June 4, 2014*
  Subject: Board comments on information presented by DOE-EM at March 2014 Board meeting.
- *Letter from Chairman Rodney Ewing to Dr. Peter Lyons, DOE Assistant Secretary for Nuclear Energy, June 5, 2014*
  Subject: Board comments on long-term dry storage of high burnup spent nuclear fuel
- *Letter from Chairman Rodney Ewing to Mr. Mark Whitney, Acting Assistant Secretary for DOE-Environmental Management, October 10, 2014*
  Subject: Board comments on information presented by DOE-EM at August 2014 Board meeting.
- *Letter from Chairman Rodney Ewing to Dr. Peter Lyons, DOE-NE; October 10, 2014*
  Subject: Board comments on information presented by DOE-NE at August 2014 Board meeting.
- *Letter from Chairman Rodney Ewing to Mr. Mark Whitney, DOE-EM; January 22, 2015*
  Subject: Board comments on information presented by DOE-EM at October 2014 Board meeting.

* For completeness, the following 2016 letters are in included in this appendix: DOE's January 2016 response to the Board's August 31, 2015, follow-up letter subsequent to the June 2015 Board meeting; DOE's June 2016 response to the Board's January 2016 report, Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program, and finally, the Board's July 2016 response to DOE-NE's June 2016 letter.

- *Letter from Chairman Rodney Ewing to Mr. John Kotek, Acting Assistant Secretary for DOE-NE; August 31, 2015*
  Subject: Follow-up on information presented by DOE-NE at June 2015 Board meeting.
- *Letter to Board from Mr. John Kotek, Acting Assistant Secretary for DOE-NE; January 27, 2016*
  Subject: DOE response to Board's August 31, 2015, letter to DOE.
- *Letter to Board from Mr. John Kotek, Acting Assistant Secretary for DOE-NE; June 9, 2016*
  Subject: DOE response to Board's January 2016 report on DOE's deep borehole research and development program.
- Letter from Chairman Rodney Ewing to Mr. John Kotek, Acting Assistant Secretary for DOE-NE; July 7, 2016
  Subject: Board response to DOE-NE's June 9, 2016, letter.

Department of Energy
Washington, DC 20585

January 30, 2013

RECEIVED FEB - 4 2013

Doctor Rodney C. Ewing
Chairman
United States Nuclear Waste
Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, Virginia 22201-3367

Dear Dr. Ewing:

Thank you for your December 11, 2012, letter providing the Nuclear Waste Technical Review Board (Board) observations and suggestions on information presented by the U.S. Department of Energy (DOE) at the Board's meeting on October 16-17, 2012. Our responses to your comments are enclosed.

Your comments on our presentations provide useful insights and we look forward to future interactions with the Board. If you require further clarification regarding any of these issues, please contact me or Jeff Williams, at (202)586-9620.

Sincerely,

Peter Lyons

Peter B. Lyons
Assistant Secretary
for Nuclear Energy

Enclosure

Printed with soy ink on recycled paper

Enclosure

Transportation, Storage and Disposal System Analyses

Board Observation and Comment

The Board observed that several comments from the public at the meeting indicated that the transportation of spent nuclear fuel (hereinafter referred to as used nuclear fuel) and high-level radioactive waste (HLW) remains a major concern. The Board noted that DOE needs to remain sensitive to this concern and address it in a candid and transparent manner.

In response to Dr. Mark Nutt's presentation regarding the development of an integrated system architecture for managing commercial used nuclear fuel from acceptance at reactor sites to disposal in a geologic repository, the Board stated that such an architecture should recognize the realities of the current situation in which the disposition pathway for the widely used dual-purpose canisters is highly uncertain and that interest in standardized canisters is growing. In the Board's view, the modeling results presented appear to be rudimentary accounting calculations that as yet do not yield particularly deep insights. Uncertainties in material flows do not seem to be represented. In addition, potential upsets in the flows are not incorporated into the modeling. The possibility of developing multiple sites, either for consolidated storage facilities or for the final repository, also is excluded from the architecture. The Board expects that these issues will be addressed as the system analyses mature.

DOE Response:

DOE is aware of the public concern regarding the transportation of used nuclear fuel and HLW, and plans to actively engage with its stakeholders to address this concern in a candid and transparent manner.

DOE agrees that the architecture should recognize that the potential disposition pathway for dual purpose canisters is uncertain and that there is some interest in standardized canisters. DOE intends to address the issues identified by the Board with the existing modeling and results will be addressed as system analyses mature.
DOE also appreciates the Board's input and suggestions regarding the development of logistics tools for simulating an integrated system architecture for managing commercial used nuclear fuel. As indicated in Dr. Mark Nutt's presentation, DOE is utilizing logistic simulation tools that have been used in previous used nuclear fuel management analyses conducted by DOE. These tools continue to be modified and enhanced, in order to reflect the current used nuclear management situation and to evaluate a wide range of potential disposition strategies. Many factors, including the ability to model multiple consolidated storage facilities and repositories, are being considered as the tools and modeling approaches evolve.

Board Observation and Comment

In response to Mr. Jeffrey Williams' presentation on the logistical and operational issues associated with the transport of stranded fuel from shutdown reactor sites, the Board noted that there would be challenges to transporting used nuclear fuel from the shutdown reactor sites. In addition, the Board noted that used nuclear fuel was largely held in storage-only casks and that there was some question about whether even the used nuclear fuel currently stored in dual-purpose casks will need to be repackaged prior to shipment. The Board urged DOE to put a high priority on developing a comprehensive plan for ensuring that cask licenses and yet-to-be fabricated casks will be available to support DOE's transportation requirements and schedule.

DOE Response:

DOE has begun a preliminary evaluation of removing used nuclear fuel from the shutdown sites and has identified many of the same challenges noted by the Board. At the nine shutdown reactor sites discussed in Mr. Williams' presentation (Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, and Zion), all used nuclear fuel is held (or will be held in the case of Zion) in canisters that are transportable and therefore would not need repackaging. There is no used nuclear fuel held in storage-only casks at these sites. The only exception to this may be six damaged fuel assemblies stored in 5 fuel canisters at the Rancho Seco site. These six fuel assemblies are stored in fuel-with-control-component-dry-shielded-canisters (FC-DSCs), not in failed fuel dry shielded canisters. Historically, the certificates of compliance for transportation casks have been updated periodically by the cask vendors and the DOE does not anticipate a problem in this area. For example, the NAC-UMS certificate of compliance was renewed by NAC in October 2012. However, DOE acknowledges that availability of transportation casks is likely to be a critical path item in any effort to remove used nuclear fuel from shutdown reactor sites. This is reflected in the recently completed draft report "Preliminary Evaluation of Removing Used Nuclear Fuel from Nine Shutdown Sites."

Board Observation and Comment

The Board expressed concern regarding an issue associated with system integration. The Board believes that many of the dry storage system designs presently in use contain material that may not meet the current criticality-control requirements for disposal and that this situation raises the possibility that these storage systems may have to be opened and the fuel assemblies transferred into containers that conform to criticality-control regulations for disposal. The Board recommends that DOE evaluate the disposal criticality control of the dry storage systems presently being loaded.

DOE Response:

DOE agrees with the Board's recommendation on evaluating disposal criticality for existing dry storage systems and has work ongoing on such an evaluation. DOE initiated work in Fiscal Year 2012 on evaluating any potential issues related to disposal of the existing storage systems, including handling and thermal output.

Evaluations of Canister and Waste-Package Temperatures

Board Observation and Comment

Enclosure

The Board observed that both the presentation by Mr. Harold Adkins on an analysis of the thermal evolution of waste packages place into dry storage and the presentation by Dr. Ernie Hardinon disposal conditions in "open" generic geologic repositories, where the emplacement media was salt, clay, and granite, were technically refined and valuable. The Board also observed that together these presentations suggest there may be more flexibility in terms of waste-package size than had previously been presumed. The Board believes this work should be continued. In particular, the two research strands should be coupled to provide temperature predictions of use fuel cladding in a waste package that has been emplaced in a drift, which could be important data if, for example, a waste package had to be retrieved.

DOE Response:

Analyses show that a range of waste package sizes (up to 32-PWR size) can be disposed of depending on the geologic medium and fuel characteristics. The numerical tools presently exist to couple heat transfer processes outside the waste package to those within to provide temperature predictions of used fuel cladding in a waste package that has been emplaced in a drift. DOE is planning to continue research to provide thermal predictions of used fuel cladding in a waste package that has been emplaced in a drift and to understand thermal evolutions.

The Importance of DOE Fully Engaging Stakeholders and Being Clear and Transparent

Board Observation and Comment

In place of the top-down models of communication that were common in the past, the Board believes that future efforts to communicate with stakeholders would benefit from an iterative, collaborative model that fully engages and involves stakeholders from start to finish. Having broad, meaningful stakeholder input throughout the process ensures that informational materials and communication products are informed by, and responsive to, the concerns and information needs of the public. In developing a plan to engage stakeholders early on, the Board urges DOE to draw upon the extensive body of literature on risk communication as well as important exemplars from successful health and environmental risk communication programs. By doing so, DOE would be able to ensure that its efforts are consistent with a consent-based approach, clear and transparent, and have a sound technical basis.

DOE Response:

DOE agrees with the Board's recommendation to engage and involve stakeholders from start to finish in an iterative and collaborative manner. In July 2012, the Office of Nuclear Energy (NE) established cooperative agreements with the State Regional Groups to collaborate with NE on issues associated with the transportation of used nuclear fuel, such as the implementation of Section 180(c) of the Nuclear Waste Policy Act, as amended, determination of preliminary routes from the shutdown sites, and development of a draft National Transportation Plan. Subtasks to support these efforts include compiling a full text bibliography of existing risk perception studies, developing an approach for a baseline risk perception study on trust, communication mechanisms, and working with the National Transportation Stakeholders

Forum's Communications Working Group to identify preferred and effective methods for discussion of highly technical and controversial topics. We anticipate involving stakeholders in drafting future communication products.

UNITED STATES
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May 28, 2013

Mr. David Huizenga
Senior Advisor for Environmental Management
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Mr. Huizenga:

On behalf of the U.S. Nuclear Waste Technical Review Board, I thank you for the participation and support of Department of Energy (DOE) Office of Environmental Management (EM) personnel at the Board's meeting in Richland, Washington, on April 16, 2013. Important technical issues were discussed at the meeting, including the eventual disposal of the DOE-owned spent nuclear fuel (SNF) and high-level radioactive waste (HLW) that currently is stored at the Hanford site. The Board regrets that you could not join us, but we appreciate that Mr. Kenneth Picha was able to present the EM program at the meeting.

Complex-Wide Overview of the DOE Office of Environmental Management

Mr. Picha provided a broad and informative overview of EM activities and responsibilities, including the strategy for managing different types of radioactive wastes, the ongoing collaboration between EM and DOE's Office of Nuclear Energy (NE) on disposal-related research concerning the feasibility of a generic salt repository, and some of the impacts on the DOE program caused by the delay in implementing a geologic repository. The overview helped the Board understand better the extent of EM's responsibilities, challenges, and accomplishments.

Classification of Wastes

A recurring and important issue that was not addressed in presentations at the meeting relates to the classification of wastes at Hanford, including the proposed separation of tank wastes into different streams for processing. Establishing the classification of the wastes would provide a technical and regulatory basis for determining the appropriate processing and disposal requirements for each waste stream. After the meeting, DOE did provide some additional information on the classification of waste incidental to reprocessing and on DOE's waste-classification authority in Guide 435.1-1. However, the information did not include a breakdown of all the waste streams at Hanford that will be subject to determinations according to the process in the Guide. Also, the waste-determination process itself was not described. Consequently, the Board requests that EM provide information on activities that have been undertaken or are planned on the classification of wastes at Hanford and other EM sites and the results of these activities to date. This will help clarify the basis for classifying the wastes that will be vitrified and disposed of in the Integrated Disposal Facility (IDF) at Hanford as low-activity waste, rather than as HLW. Classification of the wastes also will help the Board determine the extent of its technical review authority related to wastes at EM sites, including Hanford.

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Vitrification as a Complex-Wide Management Strategy

Dr. Carol Jantzen, Consulting Scientist, Environmental and Chemical Process Technology at Savannah River National Laboratory (SRNL), gave an excellent and informative summary presentation on complex-wide management practices for vitrifying HLW and noted some contrasts between the approaches used at Hanford, the Savannah River Site (SRS), and the West Valley Demonstration Project (WVDP) in New York. Her presentation of detailed technical information was a *tour de force*, making complex chemistry and physics understandable to meeting attendees, many of whom are not experts in this field.

Dr. Jantzen's presentation was followed by a panel discussion on technical experience with vitrification. Panel members Dr. Stéphane Gin of the Commissariat à l'énergie atomique (representing French experience); Mr. William Hamel, Waste Treatment Plant Assistant Manager for Office of River Protection and Federal Project Director, DOE (representing the experience of the WVDP); Mr. Jonathan Bricker, Defense Waste Processing Facility Continuous Improvement Manager SRS (representing the SRS experience); and Dr. Albert Kruger, Glass Scientist, Waste Treatment Plant Start-Up and Commissioning Integration, DOE (representing Hanford) discussed their various experiences and perspectives on vitrification. The panel was ably moderated by Dr. Werner Lutze from the Vitreous State Laboratory at The Catholic University of America (CUA).

Based on Dr. Jantzen's presentation and the panel discussion, it is clear that there are considerable differences between the chemistry of the wastes that will be vitrified at Hanford and the wastes that have been vitrified at the SRS and at the WVDP. Nonetheless, the Board believes strongly that closer collaboration among EM sites involved in waste vitrification would be mutually beneficial and recommends increased integration of their programs, possibly including the establishment of an advisory panel with representation from all three sites, to ensure that relevant experiences and lessons learned at one site are shared with the other sites. For example, it would be worthwhile for the sites to share information and/or compare approaches on (1) feed processing as undertaken at the SRS and Hanford sites, (2) feed sampling and characterization at SRS and Hanford, and (3) repository waste-acceptance criteria for glass produced complex-wide.

DOE Technology Development Programs on Waste Forms

DOE's technology development programs on waste forms also were discussed in a panel format. The panel was composed of Dr. David Peeler, Senior Fellow Engineer at SRNL; Dr. Ian Pegg, Professor of Physics and Director of the Vitreous State Laboratory at CUA; and Dr. John Vienna, Research Scientist, Pacific Northwest National Laboratory (PNNL). This panel was also moderated by Dr. Werner Lutze.

One aspect of vitrification technology development that the Board believes has particular relevance is research on the long-term performance of HLW glass. There is a clear difference between the approach used in the U.S. as presented by Dr. Jantzen and the approach used in France as presented by Dr. Gin. While the U.S. has established waste-specification criteria based on standard tests, the French have recognized that the performance of glass as a waste form can vary dramatically as a function of the dissolution and release mechanisms within the geochemical/hydrologic environments of different repository rock types.

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The Board recommends that EM consider carefully the long-term performance of glass in a variety of geologic environments, as well as the interactions of different types of engineered barriers with the glass. A specific effort also should be made to evaluate and demonstrate the long-term performance of the low-activity glass that EM plans to dispose of in the IDF. The performance of glass has been the subject of substantial research in France, and the Board believes that DOE's vitrification program at Hanford will benefit from the broad international collaboration that EM has initiated on this topic. In addition, research on the mechanisms that influence changes in glass corrosion rates with time is essential to evaluating overall repository performance, as is addressing uncertainties that could affect radionuclide release rates. A coordinated experimental and predictive modeling-simulation program could be most productive in gaining an understanding of these mechanisms, particularly in different geologic media.

In addition to the performance of the HLW glass being produced for disposal in a U.S. repository, the Board recommends that EM consider carefully the potential repository performance of the 32 glass "logs" that were produced using Hanford HLW to support the German repository program. It may be possible to evaluate the performance of the logs on the basis of the production records and the coupons that were kept at the time the logs were produced. The logs are in the form of canisters of vitrified material, which are approximately 30 cm in diameter and 120 cm long, and it is not clear that this waste form meets the product specifications for HLW glass that currently is being produced at DOE sites.

Comments by Tribal, State, and Public Organizations: Views on the Most Important Technical Issues Associated with the Eventual Disposal of HLW and SNF Stored at the Hanford Site

Representatives of tribal, state, and public organizations, including Mr. Russell Jim, Project Director of the Yakama Nation Environmental Management and Waste Management Program; Ms. Suzanne Dahl, Manager of the Tank Waste Treatment Section, Washington State Department of Ecology; Mr. Ken Niles, Nuclear Safety Division Administrator, Oregon Department of Energy (ODOE); Mr. Steve Hudson, Chairman of the Hanford Advisory Board; Ms. Pam Larsen, Executive Director of Hanford Communities; Mr. Gary Petersen, Vice President for Hanford Programs of the Tri-City Development Council; and Mr. Allyn Boldt of Hanford Challenge provided their perspectives on issues associated with the management and disposal of the SNF and HLW stored at the Hanford site. The session was moderated by Mr. Roy Gephart, a former senior program manager at PNNL and author of *Hanford: A Conversation About Nuclear Waste and Cleanup.*

Mr. Jim made the case that, because all the waste in the Hanford tanks is HLW, no waste stream resulting from processing of this waste should be reclassified as low-activity waste that would be left for near surface disposal at the site. Some of the session participants indicated they consider material that has leaked from the tanks to be HLW; this was a particular point of concern for the ODOE. While recognizing the reality of budget limitations, ODOE and other stakeholders are frustrated by the lack of progress in dealing with the issues related to Hanford's leaking tanks. The issue of *who has the authority to determine the classification of the waste* is a question that was raised by several of the session participants. In the context of the discussion above on waste classification, the answer to this question also is unclear to the Board.

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The Board found the stakeholder representatives to be knowledgeable and their comments to be extremely useful and believes that their views also should be of interest to DOE.

Hanford Site Tour

We appreciate the efforts of all involved in the Board's tour of the Hanford site on Monday, April 15. "Veterans" who have been on such tours in the past noted that this tour was one of the most comprehensive and comprehensible they had experienced. The tour provided important and useful information that helped the Board understand better the many challenges encountered by EM at the Hanford Site, as well as the significant progress that has been made over the years in remediation projects at the site. The Board gives special thanks to Mr. Richard Buel and all the other staff who were involved in planning and coordinating the tour.

Technical Poster Session

This is the first time the Board has arranged a poster session at one of its public meetings and, from the responses of the meeting attendees, the session appears to have created valuable opportunities for interaction among the public and the scientists and technical staff working on the research and development programs supporting the disposition of EM's SNF and HLW. The success of this initial experience encourages the Board to consider organizing similar events at future meetings. The Board appreciates very much the considerable effort made by Dr. Albert Kruger and Dr. John Vienna in organizing and participating in the poster session.

Once again, I thank your team and all the meeting participants who contributed to and supported this very productive meeting.

Sincerely,

{Signed}

Rodney C. Ewing
Chairman

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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May 28, 2013

Dr. Peter Lyons
Assistant Secretary for Nuclear Energy
Office of Nuclear Energy
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Dr. Lyons:

On behalf of the U.S. Nuclear Waste Technical Review Board, I thank you for participating in the Board's meeting held in Richland, Washington, on April 16, 2013. The Board particularly appreciates your making time to travel to the meeting during what we know was a busy period. Your presentation and responses to questions on the Department of Energy's (DOE) strategy for implementing the recommendations of the Blue Ribbon Commission on America's Nuclear Future were very informative, and your personal involvement in the meeting was noted and remarked on positively by many meeting attendees.

DOE Strategy for Management and Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste

The Board found your articulation of DOE's strategy for managing and disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) particularly useful because it provides a framework for the Board's future technical and scientific peer-review activities. The Board looks forward to evaluating the technical validity of DOE activities related to implementation of the strategy, and we note that almost everything in the strategy will affect or be affected by technical and scientific issues. We also observe that developing guidelines for a consent-based process for siting SNF and HLW storage and/or repository facilities will have both institutional and technical components and that the process itself will benefit from lessons that can be learned from other countries. The Board is developing a report on repository siting that we plan to release later this year, which will include a summary of international siting experience.

The DOE strategy document identifies several technical and scientific activities that the DOE Office of Nuclear Energy (NE) is undertaking in fiscal year 2013, including: (1) evaluating the potential for direct disposal of the SNF storage containers in use at utility sites in different geologic media; (2) evaluating the types and design features of back-filled engineered barriers systems and materials; (3) evaluating geologic media for their impacts on waste isolation; (4) evaluating thermal management options for different geologic media; (5) establishing cooperative agreements with other countries involved in nuclear waste management; and (6) developing a research and development plan for deep borehole disposal. As part of the Board's ongoing technical and scientific review, we look forward to learning about the status and details of these activities at future Board meetings.

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Research on Direct Disposal of Large SNF Dry-Storage Containers

The Board is particularly interested in NE's work related to the direct disposal of SNF containers currently used in dry-storage facilities at nuclear power plants. The rationale for undertaking this research was established at the Board's meeting held in Arlington, Virginia, in January 2012. The Board commends Deputy Assistant Secretary Monica Regalbuto for recognizing the merit of evaluating the potential system-wide effects of repackaging SNF for transportation and/or disposal. Dr. William Boyle discussed some of these issues at the Board meeting, and we will be interested in learning about the results of the activities NE undertakes in this area. Because repackaging of SNF for transportation and/or disposal has potential implications for the entire waste management system, the Board is planning a workshop on this subject later this year. We look forward to working with NE in arranging this event.

I would like to thank you again on behalf of the Board for your support of, and participation in, the Board's meeting.

Sincerely,

{Signed}

Rodney C. Ewing
Chairman

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UNITED STATES
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2300 Clarendon Boulevard, Suite 1300
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July 30, 2013

Dr. Peter Lyons
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Dr. Lyons:

In your presentation at the Board's April 16, 2013, meeting in Richland, Washington, you indicated that the Department of Energy (DOE) is developing a research and development (R&D) plan for deep borehole disposal as part of its *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste Disposal*. As you develop your R&D plan, the Board makes three recommendations.

- There are drilling, casing, and sealing challenges associated with the disposal of spent nuclear fuel and high-level waste in deep boreholes. The different components of the deep (5 km) borehole disposal system (e.g., drilling, emplacement and sealing) should be investigated in a logical stepwise sequence starting at the bench-scale, progressing to *in situ* tests, prior to implementing a full-scale pilot deep borehole.

- A major challenge will be the characterization of the host rock at great depth. The petrologic, hydrologic and geochemical characteristics of the rock units at depth may vary considerably. DOE should use international collaborations with those countries that have operating underground research laboratories, such as Switzerland and Sweden, to identify and address issues related to the characterization of rock at depth and to understand how the heterogeneity of petrologic, hydrologic and geochemical characteristics could affect the drilling, casing, and sealing of the proposed borehole drilling systems.

- Due to limitations on the size of the package that can be emplaced in a deep borehole, a major challenge will be the dismantling of spent nuclear fuel assemblies and the consolidation of the spent nuclear fuel rods into smaller packages. Such dismantling and consolidation will require new facilities, and

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entail additional cost and potential exposure of workers. DOE should assess these impacts as part of the deep borehole disposal R&D plan.

It is important to acknowledge that the development of deep borehole disposal systems, as described in the Blue Ribbon Commission on America's Nuclear Future report to the Secretary of Energy, would not eliminate the need for a mined geologic repository. Because deep borehole disposal is in the earliest stages of development, significant technological challenges must be resolved. Also a large number of deep boreholes would be required (the spent nuclear fuel proposed for Yucca Mountain alone would require about 600 boreholes). Because of these technological challenges and the significant scale of a deep borehole disposal program, the Board reiterates its long-standing support of mined geologic disposal and notes that virtually every national nuclear waste disposal program is pursuing development of a mined geologic repository for disposing of spent nuclear fuel and high-level radioactive waste.

As described in the enclosed update of the fact sheet on Deep Borehole Disposal, which will soon be posted on the Board's website, the technical challenges associated with drilling, emplacing, and sealing deep boreholes coupled with the scale of the effort that would be required to dismantle and package the spent nuclear fuel suggest that deep borehole disposal may prove to be extremely complex. Further, the expansion to many boreholes in different regions of the country and in different geologies make full implementation difficult. Consequently, in the Board's view, research related to deep borehole disposal should not delay higher priority research on a mined geologic repository.

The Board looks forward to reviewing DOE's work in this area at a future Board meeting.

Sincerely,

{Signed by}

Rodney C. Ewing
Chairman

Enclosure

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DEEP BOREHOLE DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

BACKGROUND

Deep borehole disposal of spent nuclear fuel (SNF) from nuclear power plants or solidified high-level radioactive waste (HLW) from the reprocessing of nuclear fuel is a concept that dates from the mid-1970s. The concept was considered again in the 1990s and early 2000s (e.g., in Sweden[1] and the UK[2]). Most recently it has been mentioned as an alternative to disposing of SNF and HLW in a mined geologic repository.[3,4] In 2012, the Blue Ribbon Commission on America's Nuclear Future (BRC) recommended further research and development to help resolve some of the uncertainties associated with deep borehole disposal.[5] The BRC particularly emphasized that deep borehole disposal might be considered for certain forms of waste that have essentially no potential for reuse.

CONCEPT

The most recent concept of deep borehole disposal being discussed in the U.S. involves drilling a borehole to a depth of about 5,000 m (about 16,400 ft) in crystalline basement rock, emplacing waste packages containing consolidated SNF assemblies or solidified HLW in the lower 2,000 m (about 6,600 ft) of the borehole, and sealing the upper 3,000 m (about 9,800 ft) of the borehole.[4] The waste packages would be emplaced individually or as a string of 10-20 packages. A single borehole could contain up to 400 waste packages, each approximately 5 m (about 16 ft) in length. Approximately 1,000 boreholes would be needed to dispose of a projected U. S. inventory of 109,300 metric tons of spent nuclear fuel and high-level waste and current plans call for a series of dense arrays of boreholes [~100 boreholes in a 2-3 km^2 (1.2-1.9 mi^2) region].[4]

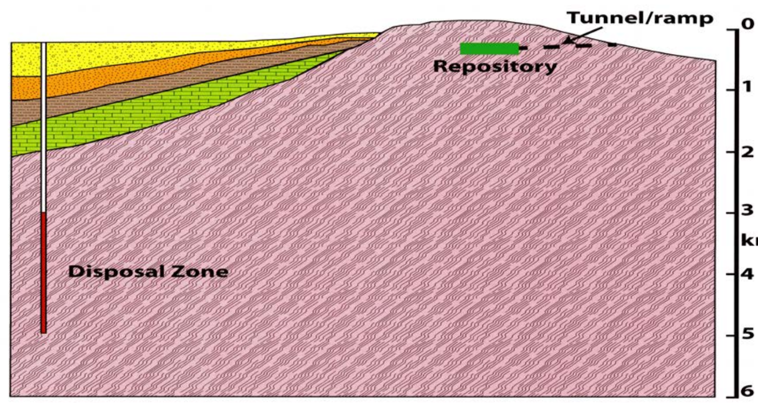

Figure 1. Schematic section of crystalline basement rock, with overlying sedimentary rocks, depicting the concept of deep borehole disposal of nuclear waste (red), in contrast to disposal in an underground mined repository (green shaded box) approximately 500 m (approximately 1600 ft) below the surface (figure modified from Gibb[6]). Crystalline basement rocks include intrusive igneous rocks such as granite and metamorphic rocks such as schist and gneiss (depicted above) and these rocks can have considerable variability in chemical and physical properties.

POTENTIAL ADVANTAGES OF DEEP BOREHOLE DISPOSAL

- Because the proposed disposal zone of a deep borehole is significantly deeper than that of a mined geologic repository (Figure 1), waste isolation from the biosphere and shallow ground water systems could be enhanced by several factors including:
  - The greater depth of emplacement
  - The low permeability of the host rock at depth, as well as greater distances to the accessible environment, which would result in very long travel times
  - The reduced buoyancy of higher density, highly saline, groundwater assumed to be present at great depth
  - The reducing conditions at depth (i.e., low concentrations of oxygen), which would result in greater geochemical isolation of the waste due to the lower solubility and mobility of some radionuclides, such as the actinides.
- Multiple disposal sites could be located near nuclear power plants with suitable geologies, thus reducing the need to transport SNF.

TECHNICAL CHALLENGES ASSOCIATED WITH DEEP BOREHOLE DISPOSAL

- **Drilling technology** – The completion of a borehole with a diameter of up to 0.5 m (about 1.6 ft) to a depth of 5,000 m (about 16,400 ft) has never been demonstrated. Doing so in crystalline rock would require the development of technologies well beyond the experience and practice of the oil industry. Deep boreholes in crystalline rock with smaller diameters drilled for scientific investigations have been plagued by complications related to spontaneous deformation of the borehole wall caused by anisotropic stress fields at depth.

- **Casing and sealing technology** – The emplacement of casing at such depth in a potentially deformed borehole and sealing of the metal casing-rock interfaces are significant technological challenges. The potential for inadequate sealing between the casing and surrounding rock is a major concern for the deep borehole concept.[7] An insufficient seal might be difficult to detect by well logging and could provide a hydraulic pathway to the surface.

- **Consolidation and repackaging of waste** – Dismantling commercial SNF assemblies that are in dry storage at nuclear utility sites would be necessary to accommodate the small size of the waste packages that could be used for disposing of SNF in deep boreholes. Repackaging SNF involves extensive fuel handling that could lead to fuel rod breakage and potential radiation exposure to workers. The criticality and thermal implications of consolidating the SNF rods also must be considered. Further, there are many types of DOE-owned SNF of various sizes that might be problematic for consolidation. In addition, existing and planned canisters of vitrified HLW are all 0.61 m (2.00 ft) in diameter and would not fit into any of the currently proposed borehole configurations.

- **Problems with emplacement of waste packages** – With the emplacement of hundreds of waste packages, the possibility of some packages becoming stuck in a borehole must be considered. Normal strategies for dealing with downhole obstacles, such as drilling through the obstructions or forcing the container down the borehole, could not be used when emplacing highly radioactive waste packages.

- **Effective borehole seals** – Effective, long-term performing materials would have to be developed and demonstrated for sealing the drill hole above the emplaced waste. A number of approaches have been proposed, such as backfilling with materials like concrete and bentonite or taking advantage of the heat produced by the waste to encapsulate waste packages in melted rock. However these approaches have not been subjected to *in situ*, underground testing.

- **Retrieval of emplaced waste** – Retrieving waste after it has been emplaced and sealed in a deep borehole would present significant technical and safety challenges. Current federal regulations require that a retrieval option be maintained after emplacement of waste in a deep geologic repository. That requirement would be difficult or impossible to meet using sealed, deep boreholes for permanent disposal of SNF or HLW.

- **Complexity of site characterization** – Implicit in most analyses of the feasibility of deep borehole disposal are the assumptions that less site characterization would be needed at great depth because conditions likely would be more homogeneous and that potentially advantageous conditions (i.e., a reducing environment, low isotropic permeability, and highly saline, density-stratified conditions) are found everywhere**.** However, surface geologic exposures of formerly mid-crustal rocks do not support these simple assumptions. Deeply buried basement rock can have considerable variability in chemical and physical properties, and there are too few well-characterized scientific deep boreholes to make these generalizations. The characterization of deep, heterogeneous crustal rocks will require the development of new geophysical techniques that can map rock properties tens of meters away from the borehole, particularly fracture zones that could channelize flow.

- **Role of multiple barriers** – A major tenet of nuclear waste disposal is the use of multiple barriers, i.e., engineered and natural barriers that work together to ensure the long-term containment of radionuclides. The strategy being developed in the U.S. for deep borehole disposal of SNF relies primarily on the geology and the depth of burial. No credit is taken for the waste package or the waste form.

CONTINUED NEED FOR A MINED GEOLOGIC REPOSITORY

The deep borehole concept, as described by the BRC, does not eliminate the need for a mined geologic repository for disposal of those waste that are deemed unsuitable for deep borehole disposal.

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THE U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

The U.S. Nuclear Waste Technical Review Board was established in the 1987 amendments to the Nuclear Waste Policy Act (NWPA). The Board evaluates the technical and scientific validity of Department of Energy (DOE) activities related to implementing the NWPA and provides objective expert technical advice on nuclear waste management to Congress and the Secretary of Energy. The Board is required by law to report its findings and recommendations at least two times each year to Congress and the Secretary.

The Board is composed of 11 members who serve on a part-time basis. Board members are appointed by the President from a list of candidates submitted by the National Academy of Sciences. By law, nominees to the Board are selected solely on the basis of distinguished professional service and eminence in a field of science or engineering.

MEMBERS OF THE BOARD

The names and affiliations of the current Board members are listed below.

Rodney C. Ewing, Ph.D., is Chairman of the Board. He is the Edward H. Kraus Distinguished University Professor at the University of Michigan in Ann Arbor, Michigan. He holds faculty appointments in the departments of Earth and Environmental Sciences, Nuclear Engineering & Radiological Sciences, and Materials Science & Engineering. He is an emeritus Regents' Professor at the University of New Mexico in Albuquerque, New Mexico.

Jean M. Bahr, Ph.D., is professor in the Department of Geoscience at the University of Wisconsin – Madison.

Steven M. Becker, Ph.D., is professor of Community and Environmental Health, College of Health Sciences, at Old Dominion University in Norfolk, Virginia.

Susan L. Brantley, Ph.D., is a distinguished professor of Geosciences and Director of the Earth & Environmental Systems Institute at Pennsylvania State University at University Park, Pennsylvania.

Sue B. Clark, Ph.D., is Regents Distinguished Professor of Chemistry at Washington State University in Pullman, Washington.

Efi Foufoula-Georgiou, Ph.D., is a distinguished McKnight University professor of Civil Engineering, the Joseph T. and Rose S. Ling professor in Environmental Engineering, and Director of the National Center for Earth-Surface Dynamics at the University of Minnesota in Minneapolis, Minnesota.

Gerald S. Frankel, Sc.D., is the DNV Designated Chair in Corrosion, Professor of Materials Science and Engineering, and Director of the Fontana Corrosion Center at The Ohio State University in Columbus, Ohio.

Linda K. Nozick, Ph.D., is a professor in the School of Civil and Environmental Engineering and Director of the College Program in Systems Engineering at Cornell University in Ithaca, New York.

Kenneth Lee Peddicord, Ph.D., P.E., is Director of the Nuclear Power Institute and professor of Nuclear Engineering at Texas A&M University in College Station, Texas.

Paul J. Turinsky, Ph.D., is professor of Nuclear Engineering at North Carolina State University in Raleigh, North Carolina.

Mary Lou Zoback, Ph.D., is a consulting professor in the Geophysics Department at Stanford University in Stanford, California.

All Board reports, correspondence, and testimony are available on the Board's website at www.nwtrb.gov.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

January 29, 2014

Dr. Peter B. Lyons
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Lyons:

The U.S. Nuclear Waste Technical Review Board appreciates the participation of U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) officials and technical experts from the national laboratories in the Board's public meeting held in Washington, D.C., on November 20, 2013. The major topics discussed at the meeting were DOE-NE's research and development (R&D) activities being supported by the Office of Used Fuel Disposition R&D (NE-53) and studies on advanced separations and waste form technologies being supported by the Office of Fuel Cycle R&D (NE-52). The presentations by DOE personnel provided the Board with a solid overview of many of the activities being undertaken by DOE-NE, while supplementary information provided by Dr. Monica Regalbuto at various points throughout the meeting was especially helpful in addressing questions that were raised.

The Board also thanks you and the other DOE officials and technical experts who participated in the "Technical Workshop on the Impacts of Dry-Storage Canister Designs on Future Handling, Storage, Transportation, and Geologic Disposal of Spent Nuclear Fuel in the United States," which preceded the Board meeting. The Board considers the disposition of spent nuclear fuel (SNF) in dry-storage systems to be an important issue that requires DOE's continuous attention. The Board is preparing a report on the subject matter of the workshop that it plans to publish in 2014.

This letter conveys Board comments and recommendations related to the DOE activities discussed at the November 20 public meeting.

Activities Sponsored by the Office of Used Nuclear Fuel Disposition Research and Development

Three topics were discussed at the meeting:

- Experiments and a field demonstration to collect data on the properties of high-burnup SNF and storage systems during long-term dry storage
- Evaluation of SNF and high-level radioactive waste (HLW) inventory and waste form/disposal options
- Integrating standardization of SNF and HLW canister system design into the nuclear waste management system

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Experiments and a field demonstration to collect data on the properties of high-burnup SNF and storage systems during long-term dry storage

Almost all the fuel that is being discharged from U.S. nuclear power plants today, and that which will be discharged in the future, is high-burnup SNF [irradiation levels greater than 45 gigawatt days per metric ton uranium (GWD/MTU)]. This high-burnup SNF likely will be stored in dry-storage canisters at commercial nuclear utility sites for decades. Dr. Michael Billone's presentation on laboratory testing of high-burnup fuel cladding alloys provided useful data on the properties of high-burnup fuel cladding. However, apparently due to funding limitations, the tests he described were limited in scope and number, were spread over a broad range of experimental conditions, and had not been repeated to investigate statistical variations in the results for the same set of conditions. These factors may limit the usefulness of the test results as the basis for predicting changes in cladding performance during transport after extended storage. Consequently, the Board encourages DOE to consider both how it can extend the work it is supporting in this area, for example by conducting more tests using cladding samples irradiated in research reactors to study the impact of high burnups, and how it can gain access to the results of work that has been done in this area by other national and international R&D programs.

During his presentation, Dr. Billone indicated that the nuclear industry has a substantial amount of additional data on the characteristics of high-burnup fuel (e.g., fuel rod end-of-life internal gas pressures that determine cladding hoop stresses, and cladding oxide-layer thickness and hydrogen pickup), but these data generally are proprietary and not currently accessible to DOE. The Board is pleased that Dr. Billone is working on projects with the nuclear industry that enables him to obtain additional data on these properties. However, given the importance of understanding how high-burnup fuel and cladding properties could change during prolonged periods of SNF storage, the Board encourages DOE to focus particular effort on gaining access to more data from the nuclear industry related to this issue.

The Board commends DOE for initiating the "Cask Demonstration Project (CDP)," presented by Dr. William Boyle, which is intended to provide much needed data on changes in the properties of high-burnup fuel and potential degradation of storage system materials during dry storage. However, the Board is concerned that the CDP does not include a more extensive program of monitoring and testing SNF and dry-storage systems during extended storage. Following the decommissioning of the Test Area North Hot Shop at the Idaho National Laboratory, DOE has no facility that can be used to open a dry-storage cask or canister in a dry environment (i.e., without submersion in a water pool) to inspect SNF following a period of dry storage. The CDP assumes the availability of such a facility, but not until ten years after the fuel has been loaded into a cask at the North Anna site, i.e., in about the year 2026. The Board recommends that DOE make it a priority to develop a more extensive program to inspect and examine, using advanced analytical techniques, the condition of SNF with a range of designs, burnups, and storage histories and establish the capability to open large dry-storage casks and canisters in a dry facility, possibly at the Idaho National Laboratory as indicated in the report "*Viability of Existing INL Facilities for Dry Storage Cask Handling*" [FCRD-UFD-2013-000027]. The Board also urges DOE to increase its R&D efforts to develop sensors and instrumentation that can operate in the extreme environments that exist in storage systems so that additional data on the condition of SNF and dry-storage systems can be collected over long storage periods.

Evaluations of SNF and HLW inventory and waste form/disposal options

The presentations by Dr. David Sassani and Dr. Peter Swift described work that DOE is doing to evaluate the attributes of potential geologic media that might be suitable for the disposal of the full inventory of SNF and HLW waste forms. However, the Board felt the waste form/disposal options evaluation lacked the in-depth analysis that would be expected from a study involving 44 individuals from 14 organizations. The final outcome of this exercise seems to indicate that the three host rock types considered for a mined geologic repository (salt, crystalline rock, and clay/shale) show similar performance, which the Board found to be surprising and questionable. At this point, the waste form/disposal options evaluation is based on qualitative metrics and appears to not address a number of issues: (1) temperature dependence of corrosion rate and mechanism for different waste forms, (2) matching waste forms to geochemical conditions in order to improve waste form performance, and (3) matching waste form performance to the half-life and radiotoxicity of different waste streams. Perhaps a useful and objective approach to improving this evaluation would be to analyze in more detail the results available in other countries: (1) Sweden for granite, (2) France and Switzerland for clay, and (3) Germany for salt. It also would have been interesting to compare the performance assessment results for each of the different geologies for a single waste form (most importantly SNF).

Given the considerable effort that went into assessing an unsaturated site in volcanic tuff at Yucca Mountain, the Board suggests that relevant results from that work should be included in the current evaluation to increase the range of the study. In addition, the Board encourages DOE to make the SNF and HLW inventory data available to the public in a more accessible format, for example in spreadsheet form.

According to Dr. Sassani's presentation, DOE's sodium-bonded fuel currently does not have a clear path for disposition. As you know, the Board is preparing a report on the management of DOE's SNF and will clarify its understanding of the potential disposition options for this fuel with DOE's Office of Environmental Management.

DOE's position with regard to the potential use of deep borehole disposal remains unclear based on the presentations and recent DOE documents. In Dr. Boyle's overview of the NE-53 R&D program, he described DOE's R&D program related to developing deep borehole disposal technology and suggested it may be used for disposal of *both SNF and HLW*. However, Dr. Swift's presentation indicated that DOE's waste form/disposal options evaluation suggests that emplacing SNF and HLW at depths of from 3 to 5 km beneath the surface is not operationally feasible because of the size of the disposal containers. The study concluded that deep borehole disposal would not be possible for large size waste packages (e.g., existing vitrified HLW containers and commercial SNF in dual-purpose canisters) and, in other cases, significant modification of waste forms would be required (e.g., rod consolidation for SNF or redesign of canisters for HLW). Prior to embarking on an expensive, full-scale demonstration, it would be prudent to have an explicit understanding of the types of waste that are realistic candidates for deep borehole disposal.

As you know, the Board provided recommendations and an updated factsheet on deep borehole disposal in its July 30, 2013, letter to you. The Board will continue to follow with great interest the deep borehole disposal R&D plans, such as described in "*Deep Borehole Disposal Research: Demonstration Site Selection Guidelines, Borehole Seals Design, and RD&D Needs*" [FCRD-USED-2013-000409] and in "*Research, Development, and Demonstration Roadmap for Deep Borehole Disposal*" [FCRD-USED-2012-000269]. At present, it appears that the current plan does not address many of the technical concerns expressed by the Board or issues raised in other critical reviews of deep borehole disposal. For example, the plan does not present the rationale for using a full-scale borehole for testing seals rather than an incremental approach beginning with laboratory-scale tests and does not indicate why the potential test program does not include drilling a pilot borehole, which was a unanimous recommendation of the drilling engineers involved in the deep borehole disposal workshop sponsored by Sandia National Laboratory in January 2013. According to the evaluation presented by Dr. Swift, deep borehole disposal has no real prospect of replacing mined geologic disposal of SNF and HLW, but it could be used to dispose of a limited class of waste forms. Thus, the use of deep borehole disposal should be expected to increase the total cost of the U.S. nuclear waste disposal program, rather than offsetting some of the cost of disposal in a mined repository. Consequently, the Board believes that DOE activities related to evaluating the potential of deep borehole disposal should not divert funding or technical effort away from work related to the storage of SNF and the development of a deep geologic repository. If DOE envisions that deep borehole disposal might be appropriate for some small volume, "niche" waste, then any borehole research program should be designed with disposal of that waste form in mind and justified on the basis of a cost-benefit and safety analysis.

Integrating standardization of SNF and HLW canister system design into the nuclear waste management system

The Board was encouraged by the effort described in Dr. Joshua Jarrell's presentation on integrating standardization into the nuclear waste management system. As you know, the Board supported the development of the transportation-aging-disposal canister for the proposed Yucca Mountain repository, and it believes now, as it did then, that the use of standardized canisters potentially may have important advantages related to safety, handling, system simplification, and cost savings. The Board strongly supports the work DOE has initiated to draw on the perspective and experience of the nuclear industry, including the cask vendors, in developing a standardized approach and looks forward to receiving further information and updates on this work as it progresses.

Activities Sponsored by the Office of Fuel Cycle Research and Development

Mr. Andrew Griffith provided an overview of NE-52, including its mission, near- to long-term program objectives, and R&D activities related to materials recovery and waste forms. However, it was not clear from Mr. Griffith's presentation how DOE establishes R&D priorities to guide the allocation of its limited funding in this area. For example, the presentation on developing the technology for uranium separation from seawater was technically interesting but, given the significant challenges facing DOE (e.g., investigating how the characteristics of high-burnup SNF change during extended periods of dry storage), and the abundance of uranium that is readily available for extraction using conventional technologies at reasonable cost, it is difficult for the Board to understand why separating uranium from seawater should be a high priority. The Board recommends that the DOE Fuel Cycle Technologies R&D program establish its priorities based on work needed to provide information on the most important issues related to managing and disposing of SNF and HLW.

Mr. Griffith highlighted DOE's support of university research through its Nuclear Energy University Program (NEUP). The Board believes that NEUP is an extremely important investment that aids in leveraging DOE funding to make technical progress and in educating the next generation of nuclear science and technology researchers. The Board strongly endorses DOE's continued support of this program.

Thank you again, on behalf of the Board, for your participation and the participation of DOE-NE staff and technical experts from the national laboratories at our November meeting and the workshop held the same week. We look forward to continuing our ongoing review of DOE's technical activities related to managing and disposing of SNF and HLW.

Sincerely,

{Signed by}

Rodney C. Ewing
Chairman

cc:
Mr. D. Huizenga, DOE-EM

UNITED STATES
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June 4, 2014

Dr. Peter B. Lyons
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Mr. David Huizenga
Senior Advisor for Environmental Management
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Dear Dr. Lyons and Mr. Huizenga:

On March 19, 2014, the U.S. Nuclear Waste Technical Review Board held a public meeting in Albuquerque, New Mexico. The main topic of the meeting was the U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) research and development (R&D) activities related to salt as a geologic medium for disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW). Technical experts from Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL) presented the results of work supported by the DOE-NE Office of Used Fuel Disposition R&D on a range of salt-related topics. These topics included the technical basis for SNF and HLW disposal in salt, performance assessment (PA) modeling of a generic salt disposal system for SNF and HLW, coupled models for thermal–hydrological–chemical and thermal–hydrological–mechanical processes in a salt repository, brine migration experimental studies in salt, and the U.S/German collaboration on R&D investigations on salt as a repository medium for SNF and HLW disposal.

Because the meeting was held in New Mexico, the Board took advantage of the opportunity to learn about the experience gained in the development and operation of the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, that might inform consideration of salt as a geologic medium for the disposal of SNF and HLW. A DOE Office of Environmental Management (DOE-EM) Carlsbad Field Office staff member discussed lessons learned from managing remote-handled radioactive wastes at WIPP and from past "generic" heater tests at WIPP that may be relevant to SNF and HLW disposal in salt. In addition, a former Director of the New Mexico Environmental Evaluation Group (EEG), which conducted independent technical evaluations of WIPP from 1978 to 2004, reviewed the history of the development of the WIPP project and discussed technical issues relevant to the construction of a repository for SNF and HLW in salt.

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After discussing and evaluating the information presented at the meeting, the Board has a number of specific comments and recommendations related to the individual presentations that are recorded in the body of this letter. In addition, the Board offers three broader observations and recommendations below based on issues that cut across the presentations.

General Observations

- The Board is impressed with the advances that DOE has made in modeling coupled processes, but believes this program would benefit from a closer coordination of effort between the national laboratories. *The Board recommends that DOE develop a framework for bringing together the different modeling groups to encourage model comparison, integration, and computational performance improvement, which are essential elements for further advances in understanding coupled processes and in increasing confidence in these models for repository site performance evaluation.*

- The Board also was impressed with the large number of published experimental studies that have been conducted in underground salt mines and repositories in the U.S. and other countries, the results of which were summarized comprehensively in one of the presentations. *Consequently, the Board recommends that DOE continue its efforts on coupled-process model validation using published laboratory and* in situ *field-scale test data.*

- Overall the presentations emphasized the potentially positive qualities of salt as a geologic medium for SNF and HLW disposal. The Board notes that there may be potential disadvantages associated with locating a repository for SNF and HLW in salt, such as inadvertent human intrusion due to exploration for natural resources (*e.g.*, oil and gas), brine migration along clay seams, and accelerated plastic flow due the presence of heat-generating waste. *The Board recommends that attention be given to these factors in order to ensure a balanced evaluation of the performance of salt as a medium for a geologic repository.*

DOE-NE Presentations

Dr. Kristopher Kuhlman (SNL) made a presentation on the technical basis for SNF and HLW disposal in salt. The presentation was very informative in that it summarized the large number of *in situ* studies in salt that previously were undertaken in the U.S. and other countries, mostly during the 1960s through the 1990s. These studies provide a wealth of data for understanding, modeling, and benchmarking the behavior of salt, including mechanical behavior, in a thermal field. The Board was impressed with the extent of the data already available for salt as a medium for geologic disposal. However, the conclusion of the talk indicated the need for data on bedded salt with waste canisters emplaced on the drift floor and covered by crushed salt backfill. *Because this emplacement strategy is one that DOE may study for SNF and HLW disposal in a U.S. repository in salt, the Board recommends collecting such* in situ *test data.*

Dr. Florie Caporuscio (LANL) described experimental studies on brine migration in salt under a thermal gradient and on thermal dehydration of accessory clay and sulfate minerals

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present in salt deposits. He also showed videos of liquid and gas-phase migration in single salt crystals under a thermal gradient. The phenomenon of brine migration by the movement of fluid inclusions up the thermal gradient was recognized many decades ago and is well documented in the literature as far back as the 1960s. In order to advance the understanding of how this would affect the performance of a salt repository, it seems appropriate to consider issues, such as the maximum amount of brine that might accumulate around a waste package as a result of fluid inclusion migration or mineral dehydration and whether any field studies have monitored migration of brine inclusions. *The Board recommends that issues of brine migration and accumulation around waste packages be addressed by initially making relatively simple calculations of the amount of water that might accumulate around a waste package due to fluid inclusion migration within the thermal gradient of a waste package.*

Dr. Philip Stauffer (LANL) described efforts to simulate coupled thermal–hydrological–chemical processes occurring within a reference HLW repository in bedded salt. The simulations used the Finite Element Heat and Mass transfer (FEHM) code, a porous-medium flow and mass-transport simulator for multiphase thermal problems that was developed at LANL. FEHM simulations were described for a generic waste disposal concept in which canisters are emplaced on the drift floor and then covered by run-of-mine salt backfill. The simulations investigated the effects of backfill saturation, backfill porosity, clay content of the salt, and heat load on in-drift temperature, porosity, and saturation. The Board considers this work to be well done, and the information presented indicates that the FEHM code will be useful in providing insights into the dominant heat and mass transport processes resulting from disposal of SNF and HLW in bedded salt. *The Board recommends expanding the application of the FEHM code to evaluate other processes, such as the effects of thin clay beds within "intact" salt on fluid and heat transport.*

Dr. Guadalupe Argüello (SNL) discussed an ongoing effort to develop a capability to simulate coupled thermal–hydrological–mechanical processes in a HLW repository in salt. The effort involves adapting for geologic repository applications the SIERRA Mechanics code suite, which is a family of finite-element, multiphysics codes developed at SNL as a simulation tool to support U.S. nuclear weapons stockpile stewardship. Dr. Argüello also described the current collaboration between DOE and German investigators to study the thermo-mechanical behavior and sealing/healing of salt and provided examples of comparisons between field data from the Asse salt mine in Germany and simulation results. He also described a scoping thermal–mechanical simulation using SIERRA Mechanics that evaluated room closure in a generic HLW salt repository. *The Board commends DOE for the significant progress that has been made in developing a state-of-the-art thermal–hydrological–mechanical model for repository applications and urges the group to continue its efforts in model improvement, including incorporation of thin clay beds that can have significant impact on mechanical performance, and, most importantly, in model validation using field data available from U.S. and international sites.*

Dr. David Sevougian (SNL) described the development of a PA modeling and analysis capability. He also explained the PA methodology (including analysis of features, events, and processes) and the PA code construction and capabilities. As there is no site-specific or design-specific information available for a U.S. repository in salt, Dr. Sevougian discussed the results of

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applying the PA code to a generic salt repository reference case. The generic PA analysis, however, did not include consideration of the potential consequences of human intrusion. As salt bodies often are located in regions rich in resources such as oil and gas, the potential for release of radionuclides from a repository as a result of human intrusion also is critically important. Other potential problems related to disposal in salt of SNF and HLW that were not included in the PA analysis include the ingress of water from sources external to the salt body, as has occurred at the Asse site in Germany, as well as the presence of pressurized brine pockets, such as those that have been found in the Castile Formation that underlies the WIPP repository. Critical issues in this regard are the cumulative volume, distribution, and properties of all the brines associated with salt deposits, from the scale of fluid inclusions to large brine pockets. *The Board recommends that the issues of human intrusion and ingress of water from sources external to the salt body be included also in a PA analysis of SNF and HLW disposal in salt.*

Dr. Frank Hansen (SNL) described the accomplishments and ongoing activities of the U.S/German collaboration on R&D investigations related to salt as a repository medium for HLW disposal. Dr. Hansen explained that U.S. and German collaboration on research, development, and demonstration activities over nearly 50 years has contributed to the comprehensive knowledge and sound expertise in salt repository science and engineering. In particular, noteworthy progress has been made on safety assessments for heat-generating waste disposal and multiphysics modeling to capture physical processes using the next generation of computational capabilities. The Board commends this collaboration in salt repository science with German investigators and other international groups such as the Salt Club, which also includes Poland and the Netherlands. The Board believes this collaboration can help DOE leverage many of its ongoing efforts, particularly the testing and modeling of WIPP salt. Drs. Hansen, Kuhlman, and Argüello discussed in their presentations the various tests that have been conducted at the Asse mine in Germany, but did not mention the flooding that has occurred there. *The Board recommends that information on the flooding that has occurred at the Asse site should be evaluated for any lessons that can inform the consideration of salt as a geologic medium for SNF and HLW disposal.*

DOE-EM Presentation

Within the scope of lessons that could be learned related to a repository for SNF and HLW in salt, Dr. Abe Van Luik (DOE Carlsbad Field Office) discussed the method of emplacement of transuranic waste at WIPP. Presently, remote-handled wastes are emplaced in pre-drilled boreholes in disposal room walls and the boreholes are then plugged with concrete shields. Using this method, the handling of one canister takes ten to twelve hours from receipt to emplacement. Also, the large equipment used to emplace the remote-handled waste blocks access to the drift, which prevents the emplacement of contact-handled waste in the open area of the same room. Because the volume of contact-handled waste that requires disposal is much greater than that of remote-handled waste, some of the boreholes for remote-handled wastes have had to be passed over and have gone unused. Dr. Van Luik indicated that DOE is looking at disposing of remote-handled waste in disposal rooms dedicated to this waste type using a simpler and more efficient single-pass mining and emplacement method. Using this method, a disposal room would be opened, remote-handled waste would be emplaced on the floor, and then the room would be backfilled with run-of-mine salt. The next disposal room would be opened only

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after backfilling of the preceding one has started. DOE is currently considering requesting permission from the Environmental Protection Agency and the State of New Mexico to use this new emplacement method at WIPP.

Dr. Van Luik also described the heater tests that were conducted in the 1980s at WIPP, which served as a surrogate for the Deaf Smith County, Texas site that at the time was being considered as a potential site for a SNF and HLW repository. The heater test results indicated that emplacement of heat-generating waste in vertical boreholes causes a steep and very localized temperature and pressure gradient to form and brine to flow into the borehole. The brine inflow was due to the pressure gradient, and the brine came from the dehydration of water-bearing clays that are interbedded with the salt. Dr. Van Luik indicated that the pressure gradient that drives brine flow can be reduced by emplacing the waste on the disposal room floor in such a way as to not cut across the clay beds. He concluded that the operational and heater test experiences at WIPP suggest that hot, higher radioactivity wastes can be disposed of safely and efficiently on a drift floor with run-of-mine salt backfill as shielding. From an operational perspective there appear to be advantages to the waste emplacement method Dr. Van Luik described. *However, the Board notes that an evaluation would be needed of whether this emplacement strategy would have any adverse impacts on the long-term performance of a SNF and HLW repository in salt.*

The Board noted that an important lesson learned from the discussion of potentially changing the emplacement method at WIPP is that during the operational phase of a geologic repository, there is still the opportunity to improve operations and, perhaps, even the long-term performance of the repository. *Thus, it is important to maintain flexibility in the design of a geologic repository and, to the extent feasible, keep options open to introduce changes after the start of operations.* This principle is important in the development of a SNF and HLW repository in any geologic medium.

New Mexico EEG Presentation

Robert Neill, Director Emeritus of EEG, provided his perspective on the history of the WIPP project and some of the technical issues that had to be dealt with during the development of WIPP as a repository. Mr. Neill emphasized that part of the success of WIPP was due to the public confidence engendered by EEG's independent evaluation of the impact of WIPP on public health and the environment. The EEG earned public confidence because it was seen as an objective, independent organization that represented the interests of the State of New Mexico. EEG published 90 reports on its analyses, made presentations at public and professional meetings, testified before the State legislature and the U.S. Congress, and encouraged its staff to play key roles in professional societies. Mr. Neill also stated that WIPP benefited from the strong support of local officials and from the commitment of the governor and the State legislature to give the project a fair review. He discussed some of the technical issues that came up during EEG's review of the WIPP project, including the need to consider the implications of the brine reservoir that was found underneath the WIPP site, mineral dissolution, and breccia pipe formation. Mr. Neill also made some observations related to SNF and HLW disposal in the U.S.

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Public Discussion

At its meetings, the Board always provides the opportunity for members of the public to comment on issues of concern related to the management and disposal of SNF and HLW. As anticipated by the Board, there was also considerable public interest at the meeting in the status of DOE activities related to the release of radioactivity from the WIPP repository on February 14. Several members of the public commented that by not having a spokesperson attend the meeting, DOE missed an opportunity to provide an update on the situation at WIPP and to respond to questions on this topic, about which many people were keenly interested.

The Board appreciates the efforts of DOE-NE and DOE-EM to prepare detailed technical presentations, and we thank all for their participation in the meeting. We look forward to continuing our ongoing review of DOE's technical activities related to managing and disposing of SNF and HLW.

Sincerely,

Rodney C. Ewing
Chairman

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UNITED STATES
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June 5, 2014

Dr. Peter B. Lyons
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Re: U.S. NWTRB Comments on the DOE Research and Development Program Related to Long-Term Dry Storage of High Burnup Spent Nuclear Fuel

Dear Dr. Lyons:

On November 18 and 19, 2013, the U.S. Nuclear Waste Technical Review Board held a technical workshop in Washington, D.C. on the *Impacts of Dry-Storage Canister Designs on the Future Handling, Storage, Transportation, and Geologic Disposal of Spent Nuclear Fuel.* The Board also held a public meeting in Washington, D.C. on November 20, 2013, which focused on the Department of Energy (DOE) Office of Nuclear Energy (NE) research and development (R&D) activities related to its Used Nuclear Fuel Disposition program. At the workshop, you presented an overview of the DOE-NE R&D program related to extended storage of spent nuclear fuel (SNF). During the public meeting, Dr. William Boyle of your staff presented more detail on the test plan for the High Burnup Dry Storage Cask Research and Development Project (CDP) being developed by a team led by the Electric Power Research Institute (EPRI) under contract to DOE. These presentations were very useful to the Board, and I thank you again for your presentation and for your personal involvement and that of your staff in the workshop and the public meeting. Initial comments on the draft test plan were included in the Board's January 29, 2014, letter to you, and you and I discussed these comments when we met on January 31, 2014.

Over the last few months, members of the Board and Board staff have attended other meetings at which the potential consequences of extended dry-cask storage of high burnup SNF were discussed, including (1) the DOE-NE Fuel Cycle Technologies Annual Review Meeting in November 2013; (2) the EPRI Extended Storage Collaboration Program (ESCP) meeting in December 2013; (3) the U.S. Nuclear Regulatory Commission (NRC)/Nuclear Energy Institute (NEI) meeting on extended storage of SNF in January 2014; (4) the NRC/DOE Public Meeting on gas sampling as part of the CDP in March 2014; and (5) the EPRI-ESCP meeting, the NEI Used Fuel Management Conference, and the National Transportation Stakeholders Forum meeting, all held in May 2014. Based on information gathered by Board members and/or staff at

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these meetings, I am providing the following additional Board comments on the CDP and the broader DOE-NE R&D program related to extended storage of SNF.

Value of the High Burnup Dry Storage Cask Research and Development Project

The Board sees the CDP as a welcome first step in investigating key issues related to the potential degradation of high burnup SNF and dry-storage systems during extended storage. The condition of dry-storage systems and the SNF they contain will need to be monitored over many decades in order to collect the necessary information for fully understanding degradation mechanisms and for calibrating codes developed to model changes in the condition of the SNF and storage systems over time. The CDP described in the test plan will provide important data to support all of these activities.

Need for Additional Instrumentation

The Board supports DOE efforts to begin monitoring the condition of SNF and storage systems sooner rather than later. However, the Board is concerned that according to the initial scope of the test plan the information to be collected during the first 10-year storage period appears to be very limited. Most of the data to be collected will be derived from measurements made during examination – using non-destructive and/or destructive techniques – of fuel pellets, fuel cladding, fuel assembly hardware, and cask components (*e.g.*, bolts and O-rings) at the beginning and at the end of this 10-year period. Originally, only cask temperature, inter-seal gas pressure, and external dose rates were to be monitored or measured during the storage period. Gas pressure measurements and gas sampling to determine the presence of fission gases, water vapor, oxygen, and hydrogen were planned to be conducted only during the two weeks after the cask is dewatered and the fuel is dried in preparation for moving the cask to the independent spent fuel storage installation (ISFSI) pad for the initial 10-year storage period. Thereafter, no measurements were initially planned that could be used to determine the rate-of-change of high burnup SNF properties or the rate of degradation of storage system materials (if it occurs). However, the final test plan published by DOE on February 27, 2014, states that "the EPRI team will continue to investigate and evaluate methods for performing gas sampling at the ISFSI during the longer-term storage period." If implemented, this sampling may be used to determine if any fuel rods fail during this period. The Board supports efforts to sample and analyze gases that may be released from the fuel rods during the 10-year storage period.

We also note that the use of advanced sensors may provide an opportunity to monitor important parameters continuously. In particular, the Board recommends the utilization or development of instrumentation that can be installed in or attached to the canister when the SNF is loaded. This would allow monitoring of the condition of the SNF and the storage system during extended storage and subsequent transportation. The Board understands that consideration is now being given to the installation of universal ports in the cask lid that would permit installation of additional internal instrumentation during periodic inspections planned over the full term of the project. The Board's view is that this will be a valuable and forward-looking extension to the planned modifications of the cask lid. If not already planned, the Board recommends consideration of basket modifications along with cask lid modifications to facilitate internal instrumentation placement. The Board understands that the development of sensors and instrumentation will take time; however, we endorse the implementation of the planned passive

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cask monitoring program at the earliest opportunity after due consideration is given to cask lid and basket modifications.

In establishing priorities for the development of sensors and instrumentation, the results obtained from models of fuel performance could be used initially to identify the most important fuel properties to be monitored. The development of long-term *in situ* monitoring systems will require innovative approaches to overcome technical challenges, including the high-radiation environment inside the cask, the need to transmit data through cask walls if no universal lid ports or other penetrations are available, and the need for power sources that could support measurements for several years or decades. At our January 31, 2014, meeting, you indicated that DOE is engaging other U.S. federal agencies, including the National Aeronautics and Space Administration and the Department of Defense, both of which have expertise in wired and wireless instrumentation, in an effort to benefit from their experiences in developing monitoring systems for harsh environments. The Board supports this initiative and encourages DOE also to look at work being undertaken in other countries that may also support these efforts. For example, the National Nuclear Laboratory in the United Kingdom is researching energy scavenging techniques that may allow the decay heat or gamma radiation from SNF to be used to power monitoring instruments fitted into SNF storage systems.

Need for More Than One Demonstration Cask

The test plan states "that a large scale R&D project using various configurations of dry storage cask systems and experiments would be beneficial." The Board agrees and believes that using a statistically meaningful number of tests – as opposed to the single cask demonstration included in the CDP – would provide additional data and confidence in the results. Tests that are initiated later in an expanded program could employ newly developed monitoring systems that can function in high radiation fields. An alternative approach might be to open, over the next few years, several casks that contain fuels with a range of burnups and storage histories to examine the condition of the fuel and the storage-system materials. Even though the information available on the initial status of the SNF in those casks may not be as extensive as that on the SNF in the CDP cask, important information could be gained from examining the condition of SNF stored in canisters that have been loaded previously. The Board understands that DOE is now considering opening other SNF storage casks or canisters, possibly during the initial 10-year storage period of the CDP, and commends DOE for being prepared to undertake this additional research activity.

Infrastructure Needs

A major issue that could affect the successful completion of the CDP is the current lack of a facility in the U.S. that can be used to unload the demonstration cask and to allow the fuel to be examined in a dry environment. Although the demonstration cask and additional systems that also may be included in the R&D program could be unloaded in existing wet pools, this would result in temperature cycling of fuel and cladding, which could alter the results obtained from examination of the SNF and make them less representative of SNF that has remained in dry storage. Consequently, the Board believes that high priority should be given to establishing a capability to open in a dry environment any of the dry-storage systems currently in use and performing the full range of inspection and monitoring operations that may be required to meet the needs of the R&D program. We note that in its fiscal year 2015 budget, DOE's request for

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the Used Fuel Disposition Program includes funding to begin to develop this capability by adapting existing facilities at the Idaho National Laboratory (INL). The Board supports this initiative.

Transportation of the Demonstration Cask

The CDP test plan indicates that certification of a cask for transportation would occur after the cask has been certified for storage and loaded with high burnup SNF. However, as the NRC's transportation requirements are separate from its storage requirements, this leaves open the possibility that the loaded TN-32 cask might not be certified for transportation by the NRC. If this were to occur, the SNF would have to be repackaged prior to shipment to the fuel examination facility, which would reduce the value of the results of the program. The Board understands that there are competing priorities in the CDP and that in the early years the emphasis will be on activities such as modifying the cask lid and examining the fuel. However, we encourage DOE to include early certification of the cask for transportation in the schedule and list of key milestones.

As DOE is aware, transportation of a loaded cask to a facility at INL for examination of the fuel and then subsequent transportation of the cask to a centralized interim storage facility or repository, also could pose problems. This is because shipment of the loaded cask to INL after 10 years of on-site storage may depend on whether the terms of the 1995 Settlement Agreement between DOE, the Navy, and the State of Idaho and the terms of the 2011 Memorandum of Agreement between DOE and the State of Idaho have been met at the time. Also, under the terms of those agreements, DOE may need to use standard canisters when the SNF is eventually transported from the INL site for storage at another facility or disposal at a geologic repository. Currently, however, the DOE standard canister design has not been certified for storage or transportation and high burnup fuel was not considered in developing the initial design for certification. In addition, no certified cask exists that can be used to transport high burnup SNF in DOE standard canisters from INL to an interim storage facility or a repository. Consequently, additional actions are necessary to ensure that the SNF can be transported away from the INL site and the Board recommends that these actions also be included in the list of key milestones.

Separate-Effects Testing and Small-Scale Testing

The separate-effects testing (SET) and small-scale testing (SST) efforts, which were listed in the draft test plan, will be crucial to understanding key factors. They also would provide a wealth of validation data. According to the draft test plan, DOE's used nuclear fuel research, development, and demonstration strategies rely on these activities in implementing the large-scale prototype testing outlined in the test plan. The Board considers it important to set priorities among the SETs and SSTs and to focus on early execution of the higher priority tests.

Additional Parameters and Measurements

According to the test plan, data on the initial high burnup fuel rod properties will be derived from destructive examination of "sister" rods taken from the symmetric partner fuel assemblies or from the fuel assemblies chosen for loading into the storage cask. However, there are many examples of fuel loadings in symmetric core locations that behave differently, so examining fuel in symmetric core locations cannot always be used to correctly infer the state of

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symmetrically located fuel. Thus, the Board suggests that extensive non-destructive post-irradiation examination of the fuel assemblies to be loaded in the cask be undertaken so that as much as possible is known about the fuel at the time of cask loading.

Loading the cask with a range of SNF burnups but the same fuel assembly design may be useful in obtaining information on the differences between the characteristics of the fuel assemblies after being subjected to identical loading, dry storage, shipping, and unloading operations. Also, data obtained from the examination of fuel in other storage systems may prove useful in determining what changes in fuel characteristics are a result of burnup and what changes are a result of transportation or unloading and repackaging operations.

Finally, more coordination with fuel inspection and analysis programs in other countries, such as the International Atomic Energy Agency Coordinated Research Project T13014 on demonstrating performance of SNF and related system components during very long-term storage, would be helpful to access potentially useful data for this program. Coordination also could accelerate progress and avoid duplication of research undertaken elsewhere.

The Board will follow the progress of the CDP with great interest and commends DOE-NE for undertaking this work. We look forward to continuing our ongoing review of the technical and scientific validity of DOE's activities in this important area.

Sincerely,

Rodney C. Ewing
Chairman

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
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October 10, 2014

Mr. Mark Whitney
Acting Assistant Secretary for Environmental Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Whitney:

The U.S. Nuclear Waste Technical Review Board held a public meeting in Idaho Falls, Idaho, on August 6, 2014. The principal focus of the meeting was the management and ultimate disposition of the spent nuclear fuel (SNF) and high-level radioactive wastes (HLW) that are the responsibility of the U.S. Department of Energy (DOE) Office of Environmental Management (DOE-EM) and Office of Nuclear Energy (DOE-NE). The Board also toured a number of Idaho National Laboratory facilities on August 5, 2014.

The Board thanks the DOE employees who prepared material for the eleven DOE-EM presentations at the public meeting and the representatives of the DOE Idaho Operations Office and its contractors who led an excellent tour of the facilities. The Board especially appreciates the considerable effort made by Barbara Beller in organizing and leading portions of the tour and for her four presentations at the meeting. The Board notes that the DOE-EM presentations were responsive to the questions the Board had provided to DOE in advance of the meeting. The Board notes and appreciates that some of the presenters provided additional information to the Board questions after the meeting.

As the Board nears completion of its report on management and disposal of DOE SNF, the information gathered at the meeting and the facilities tour will be of great value. The Board's report will review DOE SNF and SNF storage facilities at Hanford, Idaho National Laboratory, Savannah River Site, and Fort St. Vrain, and will identify technical issues that the Board believes that DOE needs to address as DOE continues to store SNF and plan for the disposal of DOE SNF.

The purpose of this letter is to provide observations and recommendations based on the Board's analysis of material presented at the meeting. These observations and recommendations are organized into two sections: (1) issues that cut across DOE-EM and DOE-NE responsibilities and (2) issues that the Board identified from presentations made by the DOE Office of Environmental Management.

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Cross-cutting Issues

The Board recognizes that DOE-EM and DOE-NE have different responsibilities; however, both offices manage SNF and HLW that will need to be disposed of in a geologic repository. Consequently, the issues of integration, transportation, and knowledge management and retention apply to both DOE-EM and DOE-NE and affect the ability of DOE to dispose of DOE SNF and HLW.

Integration

The closure of the Office of Civilian Radioactive Waste Management (OCRWM) and the subsequent suspension of most of the activities of the National Spent Nuclear Fuel Program have led to a lack of integration of activities related to SNF and HLW management. OCRWM had many responsibilities and functions (for example, transportation and disposal studies) that served to integrate both the defense and commercial SNF and HLW programs. However, it appears that some of OCRWM's responsibilities have not been explicitly reassigned within the management structure of DOE. For example, no DOE organization is explicitly responsible for research and development related to long-term disposition of DOE SNF and HLW. As compared with commercial SNF, DOE SNF is more damaged, includes many more types of fuel and cladding, and contains highly enriched uranium, all of which are important considerations when designing and implementing an integrated SNF management and disposal program. Also, DOE will need to dispose of three other solid HLW forms in addition to the vitrified HLW that has been created from commercially generated SNF and is being produced at the Defense Waste Processing Facility at the Savannah River Site. As an example, the calcined HLW at Idaho National Laboratory will be processed for geologic disposal. *The Board recommends that DOE review OCWRM's past responsibilities and functions and explicitly assign the responsibilities, that have not been already been reassigned, to specific DOE organizations to facilitate the management and disposal of DOE SNF and HLW.*

The National Spent Nuclear Fuel Program previously enabled interactions among the technical staff responsible for managing SNF at the DOE sites. The program also addressed SNF management issues that cut across the whole DOE complex. For example, until 2011 the National Spent Nuclear Fuel Program maintained the Spent Fuel Database that served as the single source of data for DOE SNF. *The Board recommends that DOE revitalize the National Spent Nuclear Fuel Program to integrate approaches at the staff-level, in order to address issues affecting the DOE SNF program, and update and maintain the Spent Fuel Database.*

Mr. Gary DeLeon, Director of the Office of Nuclear Materials Disposition (DOE-EM), provided an overview of the current and future inventory of SNF stored or planned to be stored by DOE at the Idaho National Laboratory and at other DOE sites. He noted that in order to address the challenges of managing the wide range of DOE fuel types and facilities, DOE-EM will charter a new Spent Nuclear Fuel Corporate Board. This organization will include representatives from DOE-EM, DOE-NE, DOE's Office of Science, and the National Nuclear Security Administration. Mr. DeLeon noted that one purpose of the SNF Corporate Board will be to better utilize the resources and technical capabilities for SNF management across the DOE. The Board notes that a "Corporate Board" usually establishes policy and makes budget decisions

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in order to implement policy. Both Mr. DeLeon's description of the SNF Corporate Board and the charters of other DOE Corporate Boards (for example, the High-Level Waste Corporate Board and the Tank Waste Corporate Board) suggest that the responsibility of the DOE Spent Nuclear Fuel Corporate Board will focus on coordination and cooperation on SNF management and disposition activities, and will only make recommendations to the Assistant Secretary for Environmental Management. The Board looks forward to learning more about the Corporate Board, its functions and authorities, its members, the issues it will address, and what role the Corporate Board will play in addressing the integration of SNF and HLW management and disposal activities across the DOE.

Transportation

A number of DOE-EM presentations addressed transportation of DOE SNF and HLW to a geologic repository. However, the issue of SNF and HLW transportation is a good example of how the closure of OCRWM has led to a loss of the crucial linkage between the different waste types and transportation strategies. Prior to its closure, OCRWM was responsible for designing, obtaining U.S. Nuclear Regulatory Commission (NRC) certification for, and fabrication of the transportation cask system for DOE-EM SNF and HLW. OCRWM was also responsible for the transport of DOE-EM and commercial SNF and DOE-EM and commercial vitrified HLW to a repository. Now there appears to be no clear, central coordination of transportation issues related to commercial and DOE SNF and HLW, and several presenters noted that no organization is currently charged with the responsibility of transporting DOE SNF and HLW. *The Board recommends that DOE explicitly assign responsibility for the coordination of all transportation activities for SNF and HLW.*

Knowledge Management and Retention

In an August 2013 Board report, *Review of U.S. Department of Energy Activities to Preserve Records Created by the Yucca Mountain Project*, the Board provided observations and recommendations on one part of DOE's knowledge management activities. As part of its review, the Board conducted spot checks to assess the preservation and retrievability of OCRWM's records of the Yucca Mountain Project. The report focused on records created by OCRWM in support of the Yucca Mountain project, but did not explicitly address records created by the DOE field offices responsible for the management of SNF and HLW. Under the Yucca Mountain program, these field offices would have eventually supplied the SNF and HLW *and records associated with the wastes* (for example, information on the radionuclide contents and details on packaging) to OCRWM. However, several of the DOE-EM presentations at the meeting required retrieval of information on past DOE operations and, according to the DOE-EM presenters, this proved to be difficult. *The Board recommends that DOE assess the level of record preservation and retrieval capability of DOE field office site organizations and ensure that all records related to the past management of SNF and HLW are preserved and retrievable, in order to support future waste management activities.*

Based on presentations at the meeting, it appears likely that portions of DOE's knowledge base related to past SNF handling operations and other management activities have been lost in recent years. For example, in trying to respond to a Board question on the dry cask

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storage characterization program conducted at Idaho National Laboratory during the late 1990s, no DOE employee or DOE contractor present was able to provide the details of the program. However, a member of the audience, who is no longer affiliated with DOE or its contractors, provided details on the dry cask storage characterization program during a public comment session at the meeting. Many of the key personnel who were involved in the Yucca Mountain Project and in the National Spent Nuclear Fuel Program have retired or left DOE, and very few are still available to pass on their knowledge and experience to others. This knowledge will be invaluable when determining requirements for SNF and HLW packaging, transportation, and disposal. As time passes and experienced personnel retire, there is a high likelihood that this very valuable and necessary information will be lost. *The Board recommends that DOE take early action to capture this critical knowledge so that it can be used to support later DOE efforts related to handling of the wastes, certification of transportation and storage packages, and interim storage and final disposal.*

DOE Office of Environmental Management

<u>DOE Standard Canister and Multi-Canister Overpack</u>

Mr. Brett Carlsen (Idaho National Laboratory) gave very informative presentations on the DOE SNF standard canister and on an analysis of the probability for mechanical failure from dropping the multi-canister overpacks used for SNF storage at the Hanford site. Mr. Carlsen provided a detailed history of DOE's efforts to develop a standard canister and clearly laid out the steps remaining and outstanding issues that would need to be resolved in order to complete the development of a standard canister. Specifically, he noted: (1) the challenges in designing a standard canister that could accommodate the large number of DOE SNF types; (2) the inconsistency between the assumption used for assessing criticality safety taken by DOE and the one specified by NRC regulations for SNF transportation; (3) the need to complete the development of remote canister welding technology; and (4) the need to complete the development of advanced neutron absorbers for criticality control in the geologic repository after permanent closure.

Mr. Roger McCormack of Hanford's contractor, CH2M Hill Plateau Remediation Company, described the multi-canister overpack, the process used to load the overpacks with SNF, and the scoping analyses conducted to determine potential viability for offsite shipments of the multi-canister overpacks. Mr. McCormack identified issues that would need to be resolved in order to ensure that the multi-canister overpacks could be transported offsite. Specifically, he noted: (1) the need to complete criticality analyses for multi-canister overpacks loaded with scrap baskets; (2) the need to ensure the availability of a specific commercial, NRC-certified, transportation cask in which to transport the multi-canister overpack; (3) the need to finalize the design, including a determination of the number of multi-canister overpacks within the cask and the need for impact limiters within the cask; and (4) the need to amend the certification of the commercial transportation cask to allow for transport of the multi-canister overpacks.

The Board recommends that DOE resume efforts on the DOE standard canister and multi-canister overpacks. These efforts should:

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- *Resolve criticality issues related to the transportation and disposal of the DOE standard canister. These efforts should include the submission of a topical report to NRC in order to confirm that the standard canister would be acceptable to the NRC staff as part of a transportation package based on the canister's ability to prevent intrusion of water under hypothetical transportation accident conditions.*
- *To the extent that DOE continues its generic disposal research, it should assess the viability of, and implications for, disposal of the DOE standard canister and multi-canister overpacks in different geologic settings with their associated disposal concepts (e.g., copper outer layer for a waste package in a reducing environment).*
- *Identify those issues that could impact future shipment of the multi-canister overpacks from Hanford to a geologic repository.*

Future Packaging Facility

Ms. Barbara Beller, DOE Idaho Operations Office, gave four informative presentations on the management and storage of DOE-EM-owned SNF at the Idaho National Laboratory, fuel drying experience at the Idaho National Laboratory, programs for managing aging of SNF and related facilities, and examination and transportation of damaged fuel. Many of DOE's activities related to SNF at the Idaho National Laboratory are driven by the commitments and milestones documented in the 1995 Settlement Agreement between DOE, the U.S. Navy, and the State of Idaho. It requires DOE to remove all SNF from wet storage by December 31, 2023, and from the State of Idaho by January 1, 2035, with some exceptions for SNF being maintained for purposes of testing. A 2008 addendum to the 1995 Settlement Agreement, related only to the receipt and storage of naval SNF at Idaho National Laboratory, provided additional exceptions to the 2023 and 2035 SNF deadlines. The 1995 Settlement Agreement also requires HLW that existed at the time of the agreement to be treated so that it is ready to be transported out of Idaho for disposal by 2035. Ms. Beller described DOE's approach for a future facility that would have the capability to prepare SNF for transfer from Idaho by the January 1, 2035, deadline.

Because the requirements and schedules for a consolidated interim storage facility or geologic repository for SNF are not known, it was noted by DOE personnel that plans and designs for a facility to package DOE SNF for offsite transportation, storage, and disposal cannot be finalized. Previously, DOE had considered the Idaho Spent Fuel Facility, which is licensed by the NRC but has not been constructed, as the potential packaging facility. That facility would have relied on the waste acceptance system requirements for Yucca Mountain, which included the DOE standard canister as the basis for the packaging of DOE SNF. *Regarding the plans for the management of SNF at Idaho, the Board recommends that DOE review and update the scope of the proposed packaging facility, taking into account the possibility that some SNF could be stored at the site beyond 2035, and examine how this extended period of storage could impact the capabilities needed and the timing for packaging the SNF.*

Management of Aging Facilities and SNF

Roger McCormack continued the discussion of the management of aging facilities and described the SNF management programs being undertaken at Hanford. Mr. McCormack also

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presented an overview of the SNF inventory at Hanford, including the large quantity of defense-related SNF stored in multi-canister overpacks. The Board noted significant differences in the number and scope of activities for managing aging SNF and SNF facilities at the Idaho National Laboratory and the Hanford site. For example, within the last 15 years, almost all SNF at Hanford was cleaned, dried, sealed in new multi-canister overpacks containing inert gas, and stored in a new facility. DOE monitors the gas chemistry of some of the stored multi-canister overpacks to assess degradation of the stored SNF. In contrast, most of the SNF storage facilities at Idaho National Laboratory are more than 30 years old. Some of the SNF in dry storage at the Idaho National Laboratory is not stored in an inert environment, and degradation of that SNF is not monitored. The programs for managing aging of SNF and the SNF storage facilities, at a single site and DOE-wide, do not appear to be well-coordinated or well-supported by a research and development program. As an example, the DOE research and development activities for managing aging of SNF and the SNF storage facilities at Idaho National Laboratory are focused on addressing issues associated with one DOE SNF storage facility: the NRC-licensed Three Mile Island Unit 2 Independent Spent Fuel Storage Installation. In addition, the timeline for some aging management programs appears to be linked to the duration of the current operations contract rather than the expected period of operation of the facilities. Ms. Beller stated that the Idaho National Laboratory maintains a Risk Management Plan to address challenges related to the management of Idaho's SNF. However, she noted that there are limited resources available to implement the plan.

The NRC generic aging lessons learned report for reactors [NRC 2010, Generic Aging Lessons Learned (GALL) Report — Final Report (NUREG-1801, Revision 2)] and presentations on potential generic aging management programs for dry storage systems (NRC 2014, July 14-15, 2014 meeting) provide insights for aging management programs for both wet and dry SNF storage facilities by identifying the materials subject to aging, methods for assessing the extent of aging of the different materials, and potential aging management programs (for example, for fuel performance and cask internals, concrete performance, and stress corrosion cracking). *The Board recommends that DOE develop a comprehensive system-wide strategy for managing aging SNF and SNF storage facilities and individual aging management plans for all types of SNF and SNF facilities that is based on their expected period of storage and takes advantage of the experience of the NRC's aging management programs.*

Technical Basis for Drying SNF

Both Ms. Beller and Mr. McCormack discussed experiences in drying SNF for storage at Idaho National Laboratory and Hanford. Idaho National Laboratory developed its drying process for Three Mile Island Unit 2 SNF that would be stored in unsealed storage units using extensive mock-up testing of the drying unit. Hanford relied more heavily on modelled results for the determination of the drying requirements for SNF stored in sealed multi-canister overpacks; however, at Hanford they did not focus on collecting data to understand the degradation processes that can affect stored SNF that is incompletely dried. The NRC recognizes, given that longer periods of dry storage of SNF prior to disposal will occur, that an enhanced understanding of drying of SNF storage containers is needed. For example, the NRC-funded Vacuum Drying Test Plan (Miller et al. 2013) describes experimental parameters related to vacuum drying procedures, fuel assembly and canister design features, and fuel assembly heat

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load that could be evaluated to better understand the drying process and assess how much residual water remains in a "dry" storage container. These data will be important in developing the future requirements for drying SNF for storage, transportation, and disposal. *The Board recommends that DOE collect additional empirical data in order to develop an understanding of the important processes that can occur during drying and afterwards in a sealed container with SNF that may not have been effectively dried.*

<u>Calcined HLW Waste</u>

Mr. Mark Shaw, DOE Idaho Operations Office, gave a presentation on the Calcine Disposition Project, including the background and path forward for calcined HLW stored at the Idaho National Laboratory. DOE created the calcined waste by converting liquid HLW from the reprocessing of SNF into a granular solid using a thermal process. DOE's preferred method for the treatment of the calcined waste is a hot isostatic pressing process. Mr. Shaw noted that some uncertainties still remain about the hot isostatic pressing facility's design and that hot isostatic pressed waste is not the U.S. Environmental Protection Agency (EPA) "Best Demonstrated Available Technology" for radioactive waste generated during the reprocessing of SNF. The EPA's "Best Demonstrated Available Technology" standard for this waste is vitrification and use of a "Best Demonstrated Available Technology" is a requirement contained in EPA's Land Disposal Restrictions. The Board understands that DOE will need to submit a petition to the EPA requesting that the hot isostatic pressing process be accepted as a "Best Demonstrated Available Technology". The Board remains interested in the disposition of calcined HLW waste and will follow future developments in this area.

The Board commends DOE-EM for providing the Board with the requested information, and the Board looks forward to hearing, at its next meeting, about DOE-EM SNF and HLW management activities at the Savannah River Site. The Board will continue its ongoing technical and scientific review of DOE efforts to manage and ultimately dispose of its SNF and HLW.

Sincerely,

Rodney C. Ewing
Chairman

cc: Dr. Peter Lyons
Mr. Richard Provencher

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
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October 10, 2014

Dr. Peter B. Lyons
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Dr. Lyons:

On August 6, 2014, the U.S. Nuclear Waste Technical Review Board held a public meeting in Idaho Falls, Idaho. The principal focus of the meeting was the management and ultimate disposition of the spent nuclear fuel (SNF) and high-level radioactive wastes (HLW) that are the responsibility of the U.S. Department of Energy (DOE) Office of Nuclear Energy (DOE-NE) and Office of Environmental Management (DOE-EM). The Board also toured a number of Idaho National Laboratory facilities on August 5, 2014.

The Board thanks the DOE employees who prepared material for the two DOE-NE presentations at the public meeting and the representatives of the DOE Idaho Operations Office and its contractors who led an excellent tour of the facilities. The DOE and contractor representatives provided very informative descriptions of the facilities and activities on site and gave in-depth answers to many detailed questions asked by Board members and staff.

As the Board nears completion of its report on management and disposal of DOE SNF, the information gathered at the meeting and the facilities tour will be of great value. The Board's report will review DOE SNF and SNF storage facilities at Hanford, Idaho National Laboratory, Savannah River Site, and Fort St. Vrain, and will identify technical issues that the Board believes that DOE will need to address as DOE continues to store SNF and plan for the disposal of DOE SNF.

The purpose of this letter is to provide observations and recommendations based on the Board's analysis of material presented at the meeting. These observations and recommendations are organized into two sections: (1) issues that cut across DOE-NE and DOE-EM responsibilities and (2) issues that the Board identified from presentations made by the DOE Office of Nuclear Energy.

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Cross-cutting Issues

The Board recognizes that DOE-NE and DOE-EM have different responsibilities; however, both offices manage SNF and HLW that will need to be disposed of in a geologic repository. Consequently, the issues of integration, transportation, and knowledge management and retention apply to both DOE-NE and DOE-EM and affect the ability of DOE to dispose of DOE SNF and HLW.

Integration

The closure of the Office of Civilian Radioactive Waste Management (OCRWM) and the subsequent suspension of most of the activities of the National Spent Nuclear Fuel Program have led to a lack of integration of activities related to SNF and HLW management. OCRWM had many responsibilities and functions (for example, transportation and disposal studies) that served to integrate both the defense and commercial SNF and HLW programs. However, it appears that some of OCRWM's responsibilities have not been explicitly reassigned within the management structure of DOE. For example, no DOE organization is explicitly responsible for research and development related to long-term disposition of DOE SNF and HLW. As compared with commercial SNF, DOE SNF is more damaged, includes many more types of fuel and cladding, and contains highly enriched uranium, all of which are important considerations when designing and implementing an integrated SNF management and disposal program. Also, DOE will need to dispose of three other solid HLW forms in addition to the vitrified HLW that has been created from commercially generated SNF and is being produced at the Defense Waste Processing Facility at the Savannah River Site. As an example, the calcined HLW at Idaho National Laboratory will be processed for geologic disposal. *The Board recommends that DOE review OCWRM's past responsibilities and functions and explicitly assign the responsibilities, that have not been already been reassigned, to specific DOE organizations to facilitate the management and disposal of DOE SNF and HLW.*

The National Spent Nuclear Fuel Program previously enabled interactions among the technical staff responsible for managing SNF at the DOE sites. The program also addressed SNF management issues that cut across the whole DOE complex. For example, until 2011 the National Spent Nuclear Fuel Program maintained the Spent Fuel Database that served as the single source of data for DOE SNF. *The Board recommends that DOE revitalize the National Spent Nuclear Fuel Program to integrate approaches at the staff-level, in order to address issues affecting the DOE SNF program, and update and maintain the Spent Fuel Database.*

Mr. Gary DeLeon, Director of the Office of Nuclear Materials Disposition (DOE-EM), provided an overview of the current and future inventory of SNF stored or planned to be stored by DOE at the Idaho National Laboratory and at other DOE sites. He noted that in order to address the challenges of managing the wide range of DOE fuel types and facilities, DOE-EM will charter a new Spent Nuclear Fuel Corporate Board. This organization will include representatives from DOE-EM, DOE-NE, DOE's Office of Science, and the National Nuclear Security Administration. Mr. DeLeon noted that one purpose of the SNF Corporate Board will be to better utilize the resources and technical capabilities for SNF management across the DOE. The Board notes that a "Corporate Board" usually establishes policy and makes budget decisions

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in order to implement policy. Both Mr. DeLeon's description of the SNF Corporate Board and the charters of other DOE Corporate Boards (for example, the High-Level Waste Corporate Board and the Tank Waste Corporate Board) suggest that the responsibility of the DOE Spent Nuclear Fuel Corporate Board will focus on coordination and cooperation on SNF management and disposition activities, and will only make recommendations to the Assistant Secretary for Environmental Management. The Board looks forward to learning more about the Corporate Board, its functions and authorities, its members, the issues it will address, and what role the Corporate Board will play in addressing the integration of SNF and HLW management and disposal activities across the DOE.

Transportation

A number of DOE-EM presentations addressed transportation of DOE SNF and HLW to a geologic repository. However, the issue of SNF and HLW transportation is a good example of how the closure of OCRWM has led to a loss of the crucial linkage between the different waste types and transportation strategies. Prior to its closure, OCRWM was responsible for designing, obtaining U.S. Nuclear Regulatory Commission (NRC) certification for, and fabrication of the transportation cask system for DOE-EM SNF and HLW. OCRWM was also responsible for the transport of DOE-EM and commercial SNF and DOE-EM and commercial vitrified HLW to a repository. Now there appears to be no clear, central coordination of transportation issues related to commercial and DOE SNF and HLW, and several presenters noted that no organization is currently charged with the responsibility of transporting DOE SNF and HLW. *The Board recommends that DOE explicitly assign responsibility for the coordination of all transportation activities for SNF and HLW.*

Knowledge Management and Retention

In an August 2013 Board report, *Review of U.S. Department of Energy Activities to Preserve Records Created by the Yucca Mountain Project*, the Board provided observations and recommendations on one part of DOE's knowledge management activities. As part of its review, the Board conducted spot checks to assess the preservation and retrievability of OCRWM's records of the Yucca Mountain Project. The report focused on records created by OCRWM in support of the Yucca Mountain project, but did not explicitly address records created by the DOE field offices responsible for the management of SNF and HLW. Under the Yucca Mountain program, these field offices would have eventually supplied the SNF and HLW *and records associated with the waste* (for example, information on the radionuclide contents and details on packaging) to OCRWM. However, several of the DOE-EM presentations at the meeting required retrieval of information on past DOE operations and, according to the DOE-EM presenters, this proved to be difficult. *The Board recommends that DOE assess the level of record preservation and retrieval capability of DOE field office site organizations and ensure that all records related to the past management of SNF and HLW are preserved and retrievable in order to support future waste management activities.*

Based on presentations at the meeting, it appears likely that portions of DOE's knowledge base related to past SNF handling operations and other management activities have been lost in recent years. For example, in trying to respond to a Board question on the dry cask

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storage characterization program conducted at Idaho National Laboratory during the late 1990s, no DOE employee or DOE contractor present was able to provide the details of the program. However, a member of the audience, who is no longer affiliated with DOE or its contractors, provided details on the dry cask storage characterization program during a public comment session at the meeting. Many of the key personnel who were involved in the Yucca Mountain Project and in the National Spent Nuclear Fuel Program have retired or left DOE, and very few are still available to pass on their knowledge and experience to others. This knowledge will be invaluable when determining requirements for SNF and HLW packaging, transportation, and disposal. As time passes and experienced personnel retire, there is a high likelihood that this very valuable and necessary information will be lost. *The Board recommends that DOE take early action to capture this critical knowledge so that it can be used to support later DOE efforts related to handling of the wastes, certification of transportation and storage packages, and interim storage and final disposal.*

DOE Office of Nuclear Energy

1995 Settlement Agreement

Mr. Lance Lacroix, DOE Idaho Operations Office, gave a presentation on the management of NE-owned SNF and HLW at the Idaho National Laboratory. Mr. Lacroix described the management of Advanced Test Reactor SNF and sodium-bonded SNF, including the Experimental Breeder Reactor-II SNF and the HLW forms from electrochemical processing of sodium-bonded SNF. Many of DOE's activities related to SNF and HLW at the Idaho National Laboratory are driven by the commitments and milestones documented in the 1995 Settlement Agreement between DOE, the U.S. Navy, and the State of Idaho. For example, the Settlement Agreement requires DOE to complete the transfer of all the DOE SNF from wet storage facilities to dry storage by December 31, 2023. Mr. Lacroix noted that DOE-NE SNF is presently in wet storage facilities, and he described the different challenges DOE faces, for each SNF type, in order to meet the 2023 deadline. The Board recognizes the national importance of the Advanced Test Reactor to nuclear research and to the production of cobalt-60 for medical applications and understands DOE's plans to continue operations beyond 2023. The Board is encouraged that DOE is assessing options for disposition of Advanced Test Reactor SNF. *The Board recommends that DOE assess the implications of the future generation and storage of SNF from the Advanced Test Reactor beyond 2023 on DOE's proposed packaging facility.*

The 1995 Settlement Agreement requires DOE to remove all SNF from the State of Idaho by January 1, 2035, with some exceptions for SNF being maintained for purposes of testing. A 2008 addendum to the 1995 Settlement Agreement, related only to the receipt and storage of naval SNF at Idaho National Laboratory, provided additional exceptions to the 2023 and 2035 SNF deadlines. The Board notes that DOE-NE will need to complete processing of all its sodium-bonded SNF by 2035. The 1995 Settlement Agreement also requires HLW that existed at the time of the agreement to be treated so that it is ready to be transported out of Idaho for disposal by 2035.

Because the requirements and schedules for a consolidated interim storage facility or geologic repository for SNF are not known, it was noted by DOE personnel that plans and

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designs for a facility to package DOE SNF for offsite transportation, storage, and disposal cannot be finalized. Previously, DOE had considered the Idaho Spent Fuel Facility, which is licensed by the NRC but has not been constructed, as the potential packaging facility. That facility would have relied on the waste acceptance system requirements for Yucca Mountain, which included the DOE standard canister as the basis for the packaging of DOE SNF. *Regarding the plans for the management of SNF at Idaho, the Board recommends that DOE review and update the scope of the proposed packaging facility, taking into account the possibility that some SNF could be stored at the site beyond 2035, and examine how this extended period of storage could impact the capabilities needed and the timing for packaging the SNF.*

Research and Development in Support of Extended Dry Storage of SNF

Dr. William Boyle, Director of the Office of Used Nuclear Fuel Disposition Research and Development, presented information regarding DOE's research and development efforts related to high burnup SNF and briefly discussed other DOE-NE work on "accident tolerant" fuels. *The Board recommends that in addition to evaluating the performance in the reactor of the new "accident tolerant" fuels, DOE should also evaluate how these fuel types will perform during extended dry storage and subsequent transportation and disposal.*

The Board commends DOE for its research and development efforts related to high burnup SNF, particularly given the limited funding and resources available to support it. However, given the importance of this work, the Board remains concerned that more work is not being undertaken in this and related areas, in line with the comments recorded in the Board's letter to you dated June 5, 2014. *In this respect, the Board encourages DOE to become more active in international efforts to develop a better understanding of the changes in fuel and cladding characteristics during extended periods of dry storage so that it can benefit from shared results of other research and development programs.*

DOE conducted a dry cask storage characterization program at Idaho National Laboratory during the late 1990s and DOE continues to store the commercial SNF in the casks used in that study. *As DOE reviews and updates the scope of the proposed packaging facility, the Board recommends that DOE consider the infrastructure that may be needed to support DOE's research and development efforts related to high burnup SNF and to the periodic examination of the commercial SNF that is currently in dry storage at Idaho National Laboratory.*

Poster Session

The Board appreciates the Idaho National Laboratory staff support of the poster session that followed the public meeting. The session was a valuable opportunity for interaction between the public and technical staff. The Board especially appreciates the considerable effort made by Mr. Mike Patterson in organizing and participating in the poster session on the Materials & Fuels Complex programs.

The Board will follow with interest DOE-NE efforts to manage and ultimately dispose of its SNF and HLW and its research and development efforts in support of extended dry storage of

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SNF. We look forward to continuing our ongoing review of the technical and scientific validity of DOE's activities in these important areas.

Sincerely,

Rodney C. Ewing
Chairman

cc: Mr. Mark Whitney
Mr. Richard Provencher

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

January 22, 2015

Mr. Mark Whitney
Acting Assistant Secretary for Environmental Management
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Whitney:

The U.S. Nuclear Waste Technical Review Board held a public meeting in Augusta, Georgia, on October 29, 2014, that focused on the management and plans for disposal of the spent nuclear fuel (SNF) and high-level radioactive wastes (HLW) at the U.S. Department of Energy's (DOE) Savannah River Site (SRS). These materials are the responsibility of the DOE Office of Environmental Management (DOE-EM). The Board also toured a number of facilities at SRS on October 28, 2014.

The Board thanks DOE for the participation of the many representatives of DOE Headquarters and of the DOE Savannah River Operations Office and its contractors who gave the Board an excellent tour of SRS and those who made presentations at the Board's public meeting. In advance of the meeting, the Board provided DOE with questions on several topics, indicating the Board's key areas of interest. The questions are recorded in the meeting agenda, which is posted, together with the presentation materials from the meeting, on the Board's website: www.nwtrb.gov. At the public meeting, there were 13 presentations covering the full range of topics requested, and the Board commends the presenters for explicitly addressing each of the Board's questions. The DOE and contractor representatives also provided excellent descriptions of the facilities and activities during the site tour and gave thorough answers to the additional questions asked by Board members and staff both on the site tour and during the meeting.

The information presented at the public meeting and discussed during the site tour will be particularly useful to the Board as it continues to "…evaluate the technical and scientific validity of activities undertaken by the Secretary [of Energy] … including … activities relating to the packaging or transportation of high-level radioactive waste or spent nuclear fuel" in accordance with its mandate as established in the Nuclear Waste Policy Amendments Act of 1987. The Board will also consider the information provided at the meeting in finalizing the report it is preparing on the management and disposal of DOE SNF.

The Board was impressed with the way DOE and its contractors at SRS have been successful in integrating operations at the facilities on site, including the handling, storage, and

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processing of SNF; removal and vitrification of HLW from underground tanks; and storage of the vitrified HLW in preparation for offsite disposal in a geologic repository. One example of this integration is that contractor personnel who are involved in the processing of SNF in H-Canyon provide detailed projections, in advance, of the volumes of radioactive waste to be sent to the HLW tanks for storage and subsequent processing. This allows the contractor personnel involved in HLW management to better coordinate the receipt of waste from H-Canyon with other HLW facility operations. Also, on several occasions, both during the site visit and the public meeting, DOE and contractor staff demonstrated a high level of awareness of how the operations they manage must be coordinated with operations at other facilities on site and with the overall site mission.

DOE Headquarters

DOE Corporate Boards

Mr. Jay Rhoderick, DOE-EM Associate Deputy Assistant Secretary for Tank Waste and Nuclear Material Management, gave a presentation on DOE-EM activities related to managing SNF and HLW at SRS, including an update on the establishment of the DOE SNF Corporate Board and the re-establishment of the Tank Waste Corporate Board. From his presentation, the Board understands that the term "Corporate Board" refers to an internal DOE group that has limited authority and is advisory in nature, and, is thus, different from a Board of Directors in the commercial sector, which has more extensive management and financial responsibilities.

Mr. Rhoderick described the role of DOE's Corporate Boards as providing the opportunity for sharing information and transferring lessons learned among DOE's Program Offices (e.g., DOE-EM and the Office of Nuclear Energy (DOE-NE)) and the DOE site offices. He indicated that the SNF Corporate Board will be co-chaired by representatives from DOE-EM and DOE-NE and will include representatives from the DOE Office of Science, the Naval Reactors program, the Global Threat Reduction Initiative program, and the DOE offices at the sites that manage SNF.

Integration of Programs to Manage and Dispose of HLW and SNF

Several of the presenters at the meeting addressed questions from the Board regarding the integration of the HLW activities at SRS with similar activities at the Hanford Site and the Idaho National Laboratory (INL). Based on the discussion of these presentations at the meeting and information gathered during visits to the Hanford Site in April 2013, and to the Idaho National Laboratory in August 2014, the Board concludes that the coordination of HLW-related activities at these sites, and the transfer of lessons learned between them, could be improved. While this has been noted in previous Board letters to DOE-EM and DOE-NE, it may be appropriate to record it again here, in the context of the reestablishment of the Tank Waste Corporate Board reported by Mr. Rhoderick. *Regarding the management of HLW and coordination between the DOE sites, the Board recommends that DOE place more emphasis on the exchange of lessons learned, and the transfer of new technology, such as improvements in HLW melter performance and advances in melter designs. The Board suggests that this may be an appropriate role for the Tank Waste Corporate Board.*

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As has also been recorded in previous correspondence with DOE, the Board is keenly interested in DOE's efforts to improve integration across the nuclear complex and notes that responsibility for coordination of tank waste management and disposition activities is included in the charter of the Tank Waste Corporate Board. In developing the charter of the SNF Corporate Board, the Board encourages DOE to include a similar focus on leading improvements in coordinating the management of SNF across the DOE complex and to also take account of the need to eventually dispose of DOE SNF as part of a program that will include disposal of commercial SNF, whether or not in the same repository. The Board suggests that these complex and interrelated programs are best managed by applying a systems engineering approach. In the context of DOE's SNF and HLW systems, such an approach would include a comprehensive scientific and engineering review of the functional requirements of the SNF and HLW system components, and their design, fabrication, and operation as an integrated system. This approach would also account for end-of-life considerations applicable to each of the system components and the system as a whole.

One important example of where these two Corporate Boards could together be instrumental in improving integration is in coordinating the designs of SNF and HLW containers, transportation casks, cask-handling equipment, dry storage facilities, and waste packages for emplacement in a geologic repository. The ultimate disposal of DOE SNF and HLW, as well as of commercial SNF, will require transportation in casks certified by the U.S. Nuclear Regulatory Commission (NRC). Consequently, DOE has envisioned packaging its own SNF and HLW in containers that would allow the use of commercially available transportation casks, as this would avoid having to design its own transportation casks. If DOE pursues this option, its programs for storage, transport, and disposal of SNF and HLW will need to take into account decisions, requirements, and limitations pertaining to design and licensing that originate outside of the DOE complex. *Following consideration of these issues, the Board recommends that DOE task the SNF Corporate Board and the Tank Waste Corporate Board with:*

- *employing a systems engineering approach in developing and implementing SNF and HLW management programs;*
- *obtaining design and regulatory input from outside organizations whose activities will impact the technical management of DOE SNF and HLW within the DOE complex and its preparation for off-site transportation (e.g. NRC, state regulators, local government organizations in the vicinity of the DOE sites, and commercial cask vendors);*
- *ensuring that DOE's efforts to transport and dispose of HLW, defense SNF and commercial SNF are integrated both at the management level and at the staff level, and;*
- *making DOE's efforts to integrate these activities more transparent.*

DOE Savannah River Operations Office

<u>SNF Storage at the L Basin Facility</u>

Ms. Maxcine Maxted of the DOE Savannah River Operations Office and Mr. David Rose of Savannah River Nuclear Solutions presented information regarding the storage of SNF at the

L Basin facility. They discussed the SNF inventory, expected receipts and condition of the SNF, and extended storage of SNF. Limited storage capacity is available in L Basin to receive additional SNF. However, following recent processing campaigns at H-Canyon, sufficient space exists now in L Basin to store the SNF expected to be received for at least the next three years, depending on the actual rate of SNF receipt and the rate of processing at H-Canyon.

Mr. Rose described the existing surveillance and maintenance programs that monitor water chemistry and support continued storage of SNF in L Basin. He also described the newer Augmented Monitoring and Condition Assessment Program, which includes additional surveillance of the SNF and the basin structures. This program will provide data to support the justification of the long-term use of L Basin to store SNF.

Implementation of a robust program for SNF surveillance and basin water chemistry control is very important in order to avoid the problems that were encountered during long-term storage of SNF at the K Basins at Hanford, where basin conditions were not well controlled and the SNF degraded. At Hanford, the degraded SNF proved to be very difficult to handle, dry, and package in preparation for transportation and disposal in a geologic repository. Some of the SNF in L Basin was received as cut fuel pieces that had been used in laboratory studies and other SNF arrived with damage to the cladding and/or the fuel. By maintaining a non-corrosive environment in L Basin, further degradation of the SNF can be limited. Consequently, assessing and controlling degradation of the SNF are important, especially given the possibility that not all of the SNF stored at SRS will be processed in H-Canyon, and any fuel that is not processed will have to be handled, dried, and packaged for on-site storage prior to eventual transportation to a geologic repository.

The Board notes that the existing programs for basin water chemistry control, corrosion surveillance, and monitoring of microbial growths are receiving significant management attention and are important activities to be maintained. These programs apply to both aluminum- and non-aluminum-based fuels that are stored in a variety of bundled and overpacked configurations.

DOE also has implemented many of the activities in the Augmented Monitoring and Condition Assessment Program (AMCAP), including periodic re-examination of certain SNF with techniques sensitive to detecting degradation of both the fuel material and its cladding. For example, cladding breaches and fuel corrosion can be detected by sampling water inside fuel bundle tubes, and the results from periodic reexaminations will allow DOE to better understand changes in the condition of the SNF over time. However, another planned AMCAP activity that DOE has not yet started is performance of baseline visual inspections of selected fuel, the results of which are to be recorded in photographs and videos. The Board suggests that fully implementing the remaining AMCAP activities on an early timescale is essential, as the results will provide a basis for determining what action can be taken to reduce SNF degradation and prepare some of the SNF for processing at H-Canyon or for drying and packaging in preparation for offsite transportation and disposal. *The Board recommends acceleration of the Augmented Monitoring and Condition Assessment Program to substantiate the condition of the fuel and facilitate future SNF handling, drying and packaging operations.*

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Regarding the L Basin structure, Mr. Rose described the analyses completed to assess the structural integrity of L Basin and reported that the results were documented by the Savannah River National Laboratory in the L Basin Life Expectancy Report. That report concluded that the condition of the L Basin would allow storage of SNF there for another 50 years. Mr. Rose also described the elements of the L Basin structural integrity program and presented results of the recent characterization of concrete from the retired C Basin, which is similar to L Basin in age and operating history. In this context, the Board is also encouraged to learn from Mr. Rose's presentation that SRS will complete an evaluation of the newest seismic hazards analysis at SRS and perform additional work on ground-motion models applicable to the safety analysis of the L Basin structure.

Although DOE has concluded that these activities indicate the L Basin concrete is structurally sound, it is the Board's opinion that more data should be gathered to support the technical basis for continuing operation of the facility for an additional 50 years. SRS will need to store SNF for an indeterminate length of time, and, as L Basin is the only SNF storage facility on the site, it will need to be maintained as an operational facility both for storage of SNF and to support treatment and packaging in preparation for transport and disposal. *The Board recommends that DOE consider further actions to validate the structural integrity of L Basin, including:*

- *obtaining and analyzing core samples of the L Basin structural concrete, including samples containing rebar;*
- *expanding the visual examination of the interior and exterior surfaces of the basin walls, including those areas of the exterior surface in contact with soils;*
- *obtaining and analyzing core samples of older (possibly on the order of 100 years old) representative concrete from other sources to gather data that can improve the understanding of the long-term performance of the concrete; and*
- *ensuring coordination with other efforts to study concrete aging, such as those being conducted by the DOE Light Water Reactor Sustainability Program, the Concrete Sustainability Hub at the Massachusetts Institute of Technology, and the DOE-EM Cementitious Barriers Partnership at Vanderbilt University.*

Processing of SNF at the H-Canyon Facility

Mr. Allen Gunter of the DOE Savannah River Operations Office described the design and operation of the H-Canyon facility. He also discussed recent campaigns at H-Canyon to process damaged and degraded SNF and recover highly-enriched uranium, which is being down blended to low-enriched uranium for use in fabricating fuel for commercial power reactors. This capability to process damaged SNF that may be problematic during handling and packaging for repository disposal provides DOE with options and flexibility for the management of a broad range of difficult-to-handle SNF and other nuclear materials. However, the Board notes that, as currently configured, the H-Canyon facility cannot process the stainless steel and Zircaloy-clad SNF stored in the L Basin. If this SNF is not going to be processed or shipped to INL, it will have to be dried and packaged at SRS for shipment offsite and disposal at a geologic repository.

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Alternatives for SNF Management

Ms. Maxcine Maxted described alternatives that DOE is considering for the future management of SNF at SRS. Although DOE has made no firm decisions, three primary options are available, each of which assumes the receipt of additional foreign and domestic research reactor fuel at the L Basin through 2019. The three primary options are the following:

- continued pool storage of the SNF at the L Basin facility, combined with processing of some SNF at H-Canyon
- processing of all aluminum-clad fuel at H-Canyon and transfer of non-aluminum-clad fuel to INL
- drying, packaging, and on-site dry storage of all SRS SNF until it can be transported off-site to a consolidated interim storage facility or a geologic repository

If DOE does not modify H-Canyon to enable the processing of non-aluminum-clad SNF, that fuel will have to be prepared for onsite storage or transportation offsite. This preparation includes drying and packaging, and, as there is no facility currently available at SRS that could be used for these operations, DOE would need to modify an existing facility or construct a new facility to provide this capability. In discussing the potential requirement for drying and on-site storage of SNF, Ms. Maxted stated that one option DOE has is to resume work on developing the L Area Basin Isolation System that was developed as a concept in preparation for packaging this fuel for transportation to INL. However, Ms. Maxted stated that work on this system is not currently funded by DOE, and she does not expect funding for it to be provided in the near future.

If SNF at SRS is to be packaged for off-site transportation and disposal, DOE plans to use commercially available SNF drying processes and container designs where possible, and plans to ensure that the packaged SNF is "road ready," *i.e.*, that the containers are licensed for transportation. Ms. Maxted stated that SRS may use the multi-canister overpack design employed at the Hanford Site for packaging SNF. However, as the Board noted in its October 10, 2014, letter, the multi-canister overpack design is not yet licensed for transportation, and technical questions remain regarding whether it can be licensed for transportation. It is not clear to the Board whether SRS has considered using the DOE standard canister that was intended as a common design for storage, transportation, and disposal of all DOE-owned SNF other than the Hanford SNF that is already stored in multi-canister overpacks.

Based on the presentations regarding the management of SNF at SRS, the Board observes that there is significant uncertainty associated with DOE's plans for the ultimate treatment and disposal of the SNF. Although DOE decided, in 2013, to process approximately 3.3 metric tons of a projected 22 metric tons of SNF through H-Canyon, there are no firm plans regarding processing of the remaining SNF. In considering the options for processing or disposal of the remaining SNF, DOE should take into account the difference in the projected release of radionuclides according to the physical form and the chemical composition of the alternative waste forms in different geologic environments.

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Although the impacts of the defense wastes in a combined defense/commercial waste repository would be overshadowed by the impacts of the large quantity of commercial SNF, the waste form will be especially important if DOE decides to pursue a defense-waste-only repository. *The Board recommends that DOE perform a study to compare the performance of DOE SNF and vitrified HLW in different geologic environments. The results of this work should then be used to inform plans for processing SNF in H-Canyon.*

<u>Processing of HLW and Integration of Activities Across the DOE Complex</u>

Eight of the presentations at the meeting were related to the management of radioactive wastes at SRS, including processing of HLW at the Defense Waste Processing Facility, plans for processing waste streams from the new Salt Waste Processing Facility, storing the resulting canisters of vitrified HLW, integration of all associated activities, and lessons learned. The presenters were Jean Ridley of the DOE Savannah River Operations Office; Jonathan Bricker, Peter Hill, Dan Iverson, Vijay Jain, and Brenda Green of Savannah River Remediation; and David Peeler and Sharon Marra of the Savannah River National Laboratory. The Board appreciated the detailed presentations provided by these speakers and the commendable approach that they used to display clearly the integrated system of all SRS HLW management facilities and operations. Each speaker identified where the subject of their presentation fit into the integrated system. The Board also observed a notable practice at the Salt Waste Processing Facility where the plant operations staff is working with the construction and testing staff during construction to ensure that the requirements of the operations staff are incorporated into the design and construction of the facility. The project managers at the facility indicated that they expected this input would play a major role in avoiding problems during the startup and operation of the facility.

Ms. Ridley's presentation on the storage of vitrified HLW canisters highlighted that DOE continues to follow the requirements of the Waste Acceptance System Requirements Document (DOE/RW-0351, Rev. 5) and the Quality Assurance Requirements and Description document (DOE/RW-0333P, Rev. 21). The Board notes that although these documents were developed as part of the Yucca Mountain Project, they form a solid foundation for development of the technical information needed to support a license application and safety analysis for any future geologic repository for the final disposal of DOE's SNF and HLW.

Finally, the Board observes that DOE and its contractors at SRS have been successful in coordinating a broad range of nuclear facilities on site that together represent most of the back-end of the nuclear fuel cycle: storage and processing of SNF, vitrifying HLW and storage of the vitrified product, and disposing of low-activity radioactive waste. A particular practice at SRS that could serve as a useful example for other DOE sites is the issuance of a periodic Liquid Waste System Plan that clearly explains the interrelationships between, and the coordination of, all the HLW facilities. The Board is therefore encouraged to learn that DOE intends to utilize contractor technical exchanges and the availability of the DOE Corporate Boards to improve communication among all the sites and to encourage the transfer of lessons learned, including lessons learned at SRS.

On behalf of the Board, thank you again for the participation and cooperation of the representatives of DOE-EM, the Savannah River Operations Office, and DOE's contractor organizations. We look forward to continuing our ongoing review of DOE's technical activities related to managing and disposing of SNF and HLW.

Sincerely,

{Signed by}

Rodney C. Ewing
Chairman

cc: Dr. Peter B. Lyons
Dr. David C. Moody, III

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201–3367

August 31, 2015

Mr. John Kotek
Acting Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Mr. Kotek:

The Nuclear Waste Technical Review Board (Board) held its 2015 Summer Meeting in Golden, Colorado, on June 24, 2015, to review U.S. Department of Energy (DOE) activities related to the transportation of commercial spent nuclear fuel (SNF). The public meeting included speakers from DOE, the U.S. Nuclear Regulatory Commission (NRC), national laboratories, and the Swiss energy company, Axpo. The meeting also included a panel discussion on the potential for corrosion of canisters used for the storage of SNF. Board observations and recommendations from the meeting are discussed below.

The Board thanks your staff for its work in preparing for the public meeting and for providing several of the informative presentations. The speakers did a good job of addressing the specific questions that the Board provided in advance of the meeting. The questions helped focus the discussions on the technical issues of most interest to the Board and provided a useful context for the public audience. The Board also appreciates the investment of time and effort by DOE and laboratory personnel who developed posters for the poster session that followed the public meeting. The Board notes the good turnout by the public in Golden and via webcast and values the comments made by the public at the meeting. The agenda for the public meeting (including questions posed to DOE), the meeting transcript, and a video recorded during the webcast are all available on the Board's website at www.nwtrb.gov/meetings.

Transportability of Spent Nuclear Fuel from Operating Nuclear Power Plant Sites

Ms. Melissa Bates, of the DOE Office of Nuclear Energy (DOE-NE), presented details of the Nuclear Fuel Storage and Transportation Planning Project. During her presentation, Ms. Bates explained the status of SNF storage at both operating and shutdown nuclear power plant sites and identified those SNF canisters and casks that are licensed for storage only and those that are licensed for both storage and transportation.

Ms. Bates stated that DOE is making good progress on evaluating technical issues associated with transportation of commercial SNF from shutdown sites and has determined that there are no significant technical issues that would prevent the transportation of SNF from those sites in the canisters or casks in which the SNF is currently stored. She noted that it will be necessary to resolve some technical issues before SNF stored at some operating nuclear power plants can be transported. For example, Ms. Bates pointed out that 12 sites with operating commercial reactors are storing SNF in a total of 427 canisters and casks that are currently licensed for storage only, and that collectively, these canisters and casks hold 11,019 SNF assemblies. For the majority of these canisters and casks, however, Ms. Bates said that DOE's evaluation shows no insurmountable technical challenges that would prevent them from being licensed for transportation.

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Mr. Meraj Rahimi, of the NRC, discussed differences between the regulatory requirements for storage and for transportation of SNF canisters and casks. He stated that, in a few cases, problems have been encountered in obtaining certificates of compliance for transportation of canisters that are currently licensed for storage of SNF. An example cited by Mr. Rahimi was the failure of certain internal components of the VSC-24 canister to meet structural integrity criteria after a 30-foot drop test. As a result, the canister did not receive a certificate of compliance for transportation. Nuclear utilities using VSC-24 canisters will have to find an alternative for transporting SNF stored in these canisters.

The Board observes also that many nuclear utilities are loading SNF into very large capacity canisters—the largest canister in use today can store as many as 37 pressurized water reactor (PWR) assemblies or 89 boiling water reactor (BWR) assemblies. For example, the Holtec International MPC-37 canister can hold 37 PWR assemblies and, when loaded, weighs 116,400 pounds, excluding the substantial weight of a transportation overpack. The weight of the combined canister and overpack will exceed the capacity of standard transportation methods, and the load will have to be transported by a heavy-haul tractor-trailer or by rail on a specially-designed rail car. The size and weight of these and similar loads may prevent transporting SNF, or limit the road or rail route options for transporting SNF, particularly from operating nuclear power plant sites.

The Board commends DOE-NE for its efforts to assess and fully understand the transportability of SNF now stored at shutdown nuclear power plant sites. However, the Board notes that technical challenges remain regarding the transportability of SNF now stored in canisters and casks at operating nuclear power plants. In particular, the regulatory requirements for transportation of commercial SNF[1] *and certain commercial SNF canisters*[2,3] *may be difficult to meet. DOE would be well-served to address these technical challenges sooner rather than later. The Board recommends that DOE-NE work closely with nuclear utilities and the NRC to expeditiously define and resolve technical issues that may limit or prevent the transportation of SNF in current canisters and casks from nuclear power plant sites. As a result of such consultation, if repackaging of the SNF is determined to be necessary, it is more likely that the site infrastructure to support repackaging would still be in place.*

System-Level Analyses and Stakeholder Engagement

During her presentation, Ms. Bates summarized five major computer-based tools that DOE is developing to assist in the integration and analyses of the SNF storage and transportation programs:

- Multi-Objective Evaluation Framework (MOEF)
- Next Generation System Analysis Model (NGSAM)
- Execution Strategy Analysis (ESA)
- The Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS)
- Stakeholder Tool for Assessing Radioactive Transportation (START)

Ms. Bates provided a high-level overview of these five tools, which appear to be potentially valuable in helping DOE plan for transportation of SNF. However, information regarding the detailed structure and

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[1] The NRC provides the requirements for the transportation of spent nuclear fuel in Title 10 of the Code of Federal Regulations, Part 71, *Packaging and Transportation of Radioactive Materials* (10 CFR 71) and regulates the application of the requirements; specific requirements for SNF are contained in 10 CFR 71.33, *Package Description*, and 10 CFR 71.55, *General Requirements for Fissile Material Packages*.

[2] For transportation of canisters and casks holding SNF, 10 CFR 71 includes specific requirements for containment of radioactive materials, criticality control, SNF retrieval, thermal loads, and dose rates.

[3] If a canister is relied on to provide moderator (water) exclusion from the canister to prevent criticality during transportation, then the canister must meet additional requirements associated with maintaining its structural integrity to preclude flooding the canister with water, even under accident conditions.

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planned use of some of the tools was not readily available. Based on discussion during the meeting, it appears that the UNF-ST&DARDS and, in particular, its unified database, represents a significant resource that will become increasingly valuable in standardizing DOE's planning and analysis, and as a safeguard against the loss of institutional knowledge as experienced personnel retire. In previous letters to DOE, *e.g.*, the letter, Ewing to Lyons, January 29, 2014, the Board has recommended that DOE make data such as the unified database available to the public in an easily accessible format, subject to security restrictions.

The Board would like to learn more about the tools, including the UNF-ST&DARDS. Additionally, the Board suggests that demonstrating the tools to local communities and making the related documentation available would improve stakeholder engagement. In particular, the START program, if provided in a modified form to avoid security issues, could be an excellent tool to help stakeholders understand the basis for selecting different routing options for the transportation of SNF.

Mr. Jim Williams, of the Western Interstate Energy Board, gave a presentation on stakeholder perspectives regarding the transportation of commercial SNF. According to Mr. Williams, DOE has improved its outreach efforts to stakeholders who have an interest in the transportation of SNF. For example, during one of its site assessments, DOE invited members of interested stakeholder groups to visit a shut-down nuclear power plant site, where the only remaining activity is the storage of SNF in dry-storage casks.

However, Mr. Williams maintained that much of DOE's focus continues to be on siting a repository for SNF and high-level radioactive waste, and that less attention has been paid to the issues related to the transportation of nuclear wastes to a repository. He suggested that the views of some stakeholders, such as the communities along the proposed SNF transportation routes, should receive more attention. These "corridor communities" will be subjected to the risk associated with the transportation of SNF through their areas, but they may not receive any benefits. He urged early engagement with stakeholders to clearly explain the purpose, mission, and importance of the SNF transportation plan, including interim steps such as the addition of a consolidated interim storage facility.

The Board recommends that DOE expedite its efforts to finalize and publish documentation supporting its integration and planning tools associated with the transportation of SNF. The Board also recommends that DOE consider producing a version of START that is not restricted in its release, so that it can be demonstrated and provided to members of the general public in order to increase their understanding of the constraints on routing options for the transportation of SNF. Such an effort should be initiated early in DOE's route selection process and be used to clearly explain all aspects of DOE's plans.

Chloride-Induced Stress Corrosion Cracking Under Dry-Storage Conditions

Dr. Robert Einziger, of the Board's senior professional staff, moderated a panel discussion on the potential for chloride-induced stress corrosion cracking (CISCC) of dry-storage canisters. The panel members included of Dr. David Enos, Sandia National Laboratories; Mr. Joe Carter, Savannah River National Laboratory; Dr. Steve Marschman, Idaho National Laboratory; Dr. Shannon Chu, Electric Power Research Institute (EPRI); and Mr. Meraj Rahimi, NRC. Dr. Einziger explained that CISCC requires three conditions for crack initiation and growth: a susceptible material such as austenitic stainless steel, high tensile stresses in the material, and the presence of wet chlorides in contact with the material. These three conditions can be found at some of the dry-storage locations for commercial SNF.

Most dry-storage canisters are fabricated from austenitic stainless steel (304, 304L, 316, or 316LN stainless steel) and closed by welding on a stainless steel lid. Welding can create a heat-affected zone in the steel that is susceptible to various forms of corrosion including CISCC if the residual tensile stresses are sufficiently high and the local environment is sufficiently aggressive. The locations of many dry storage sites at reactors are especially vulnerable to chloride aerosol deposition and high humidity, which could combine to create conditions conducive to CISCC on the canister surfaces. Dr. Chu indicated that, whereas CISCC has not yet been found on any dry-storage canisters, it has been found in steel structures in similar

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atmospheric conditions. Given the possibility of high crack propagation rates from CISCC and extended dry-storage times, this issue requires attention. For example, a crack growing at 0.5 millimeter per year, which is possible under aggressive conditions, would penetrate the wall of a susceptible stainless steel canister in 25–50 years.

Cracking of sensitized stainless steel under immersion conditions has been studied in detail, but this cracking phenomenon is much more complicated under atmospheric conditions where the susceptibility of the canisters to cracking will depend on several complex factors. The local environment on the canister surface is critical, but is variable and not well understood under atmospheric conditions. For example, magnesium chloride, a component of sea salt that can become airborne in droplets, will deliquesce (transform to a concentrated liquid by absorbing moisture from the air) at 35% relative humidity to create a very aggressive aqueous environment even under relatively dry conditions. However, Dr. Enos described chemical analyses performed on samples taken from the surfaces of canisters at three sites located in brackish or marine atmospheric environments, and the chloride concentrations were either very low or much lower than expected. Dr. Enos suggested that the apparent absence of cracking of the dry-storage canisters might be associated with the low chloride concentration. The chloride ions deposited from aerosols on the surface of a canister may be depleted while dry (*e.g.*, decomposition of ammonium chloride into ammonia and hydrogen chloride gas) or they may be depleted after they have deliquesced in the presence of humidity to form hot brine. Dr. Enos suggested a mechanism by which chloride ions in the hot brine are converted to volatile hydrogen chloride, which could then degas from the surface to leave a much less aggressive environment. However, this mechanism has not been proven and even very small concentrations—parts per billion—of dissolved hydrogen chloride (hydrochloric acid) can be very corrosive. Thus, the local environment on canisters, including chloride concentration, temperature, and local humidity, must be understood in order to develop meaningful models. Dr. Chu indicated that models have been developed, but they were based on limited data, such as those from a Japanese study (conducted by the Central Research Institute of Electric Power Industry[4]), which used salt solution dropped onto steel samples under tensile stress. Such accelerated tests using conditions that are more aggressive than realistic environments must be carefully assessed to ensure that the failure mechanism has not been changed.

Much of the analysis to date in submerged environments has focused on the crack growth rate of CISCC in austenitic stainless steel, with the assumption that surface flaws and cracks will exist and that the initiation stage will not be rate-determining. Therefore, it is important to understand the dependence of crack growth rate on the environmental factors during atmospheric exposure. However, the crack initiation stage, including pit formation and pit-to-crack transition, is much harder to study. This early stage may be the rate-limiting step in the overall failure process.

The state of stress at the welds and the resultant stress intensity at defects or corrosion pits are also critical for assessing the susceptibility to CISCC. It is not uncommon for residual stress to vary through the thickness of a component such that a tensile stress at the surface becomes a compressive stress at the interior, thus stifling crack growth and preventing penetration of the wall. Dr. Enos described ongoing experiments on a mock-up canister to assess the three-dimensional stress state. He indicated that some models predict the formation of short cracks perpendicular to the welds, which might impede further crack growth and not pose integrity concerns. The mock-up experiments will be very useful for validating such models.

The final important aspect of this issue is inspection. Dr. Marschman stated that dry-storage systems in use were not designed to allow for inspection. The size and position of vents in the overpacks as well as the high radiation field and temperature make inspection extremely difficult. Fully-automated inspection systems are not yet available; thus, inspection equipment is manipulated through the vents by hand. Based

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[4] K. Shirai and J. Tani, 2011, "Study on Interim Storage of Spent Nuclear Fuel by Concrete Cask for Practical Use, Feasibility Study on Prevention of Chloride Induced Stress Corrosion Cracking for Type304L Stainless Steel Canister", CRIEPI Report N10035 (in Japanese).

on the panel discussion, DOE appears to be applying resources through the Nuclear Energy University Program (NEUP) and the Integrated Research Program (IRP) at Pennsylvania State University and other schools to develop new systems for the inspection of the surfaces of canisters.

In the future, there are good opportunities for canister vendors to apply stress-relieving treatments to welded canisters or fabricate new canisters from materials that are not susceptible to CISCC. In addition, dry-storage systems could be designed to facilitate inspection of the SNF canisters.

The time allocated at the meeting to the discussion of CISCC of dry-storage canisters was insufficient for the Board to gain a full appreciation of the topic and the activities of DOE in this important area. The Board plans to gather additional information from DOE, EPRI, and other sources in order to more fully understand the phenomenon of CISCC under atmospheric conditions.

In the meantime, the Board recommends that DOE-NE continue to work with EPRI and NRC, but assume a greater leadership role in integrating research and development being performed by multiple organizations on CISCC of dry-storage canisters, particularly in 1) determining the environments on canister surfaces, 2) assessing the state of residual stress in the welded canisters, 3) determining the time interval until crack initiation under current storage conditions, 4) confirming crack growth rates, and 5) developing robust inspection tools and methods appropriate for the conditions and requirements of dry-storage systems.

Regarding other research needs associated with commercial SNF, the Board recommends that DOE-NE expand its leadership in the identification and communication of technical gaps, technical information needed to fill the gaps, and research being done related to commercial SNF wet storage, drying, dry storage (onsite or centralized), transportation, and repackaging (if needed).

Standardized Transportation, Aging, and Disposal Canisters

Dr. Josh Jarrell, of the Oak Ridge National Laboratory, presented information about DOE's evaluation of the feasibility and potential benefits of using a standardized transportation, aging, and disposal (STAD) canister for commercial SNF. The use of such a canister can offer the benefits of common handling equipment, common transportation equipment, and common procedures and training programs—features that can potentially improve operational efficiency and reduce overall program cost. However, the potential benefit would be significantly less if STAD canisters are introduced after much of the SNF has been moved into large dry-storage canisters.

Dr. Jarrell described recent activities, including collaboration with nuclear utilities and vendors, to assess the time and cost of using STAD canisters for dry storage of commercial SNF when the fuel is removed from wet pool storage. He noted that, by September 2015, his team expects to report their recent findings on the impacts of using STAD canisters, and, in fiscal year 2016, to issue a final report on all STAD canister impacts.

During the question and answer sessions at the public meeting, DOE representatives clarified that, if implemented, the STAD canister would be used to package commercial SNF taken directly from the spent fuel pools of commercial nuclear power plants. The STAD canisters would not be used for SNF that is currently stored in large dry-storage canisters since this would involve a significant effort to open the welded canisters, transfer the SNF, and dispose of the old canisters (more than 89,000 SNF assemblies are now loaded in 2200 dry-storage canisters and casks[5]). Instead, the SNF now in dry storage would remain stored until transported in its current storage canisters and casks (if licensed for transportation) to an interim storage facility or a geologic repository. Depending on the repository design, the condition of the dry-storage canisters and their contents, and the expected form of a disposal package for SNF, it may be necessary to

[5] Values reported in *UxC Store Fuel*, Volume 16, No. 204, UxC, August 4, 2015.

repackage the SNF from existing dry-storage canisters into disposal containers (possibly incorporating the STAD canister) at an interim storage facility or the repository site.

Dr. Tony Williams, from the Swiss energy company, Axpo, presented a description of SNF management efforts in Switzerland. In particular, he provided detailed information about the use of thick-walled dual-purpose storage and transportation casks for commercial SNF in Switzerland [unlike thin-walled SNF storage canisters inside thick-walled storage overpacks or vaults that are commonly used in the U.S.]. Originally, the Swiss program used only one type of storage and transportation cask for all of its SNF—essentially, a standardized cask. However, this cask and its successors (*e.g.*, the Areva TN®97L and TN®24BH casks) are expensive because of their robust design, including thick shielding and steel walls, and because they need to be maintained to remain qualified for transport. Dr. Williams pointed out that it is not cost-effective to use these casks primarily for storage. He also noted that international regulations for transportation of SNF are updated approximately every five years and that some casks originally licensed for transportation may not meet the new requirements. For this reason, and to allow for greater flexibility in the SNF management program, the Swiss utilities are now looking at procuring a less-expensive dry-storage system that includes a welded, thin-walled SNF canister that can be stored in a storage overpack, and then transferred into a transportation overpack for shipment.

It has not yet been decided whether to use a STAD canister for the nation's commercial SNF, nor has DOE fully defined the purpose, scope, costs, benefits, and timing of the use of such a canister. Without this information, conducting a system-level evaluation of the impacts of implementing STAD canisters is challenging and could have large uncertainties. Therefore, the Board recommends that DOE continue working closely with nuclear utilities to examine the implications of using a STAD canister, including the impacts of implementing a STAD canister at different times and at different repackaging locations (if repackaging is needed).

Tour of the Transportation Technology Center

In conjunction with, but not directly related to the public meeting, several Board members and staff members joined John Herczeg, Deputy Assistant Secretary of Fuel Cycle Technologies in the DOE Office of Nuclear Energy, and other DOE staff and contractors on a tour of the Transportation Technology Center, near Pueblo, Colorado, on June 23, 2015. The tour was planned and coordinated by the Office of Nuclear Energy. In particular, Ms. Erica Bickford (DOE-NE staff member) did an excellent job organizing the tour and coordinating the associated logistics for both DOE personnel and Board members and staff.

The Board members and staff who joined the tour found it informative. The facility personnel provided detailed explanations of the facilities and systems used to test rail transport equipment. They demonstrated a good understanding of DOE's interest in the transportation of SNF and focused the presentations and facility tour on this aspect of rail transport. The information gathered during the tour provided important insights into the planning needed to support the transportation of SNF by rail.

Thank you again, on behalf of the Board, for the participation of DOE-NE staff and technical experts from the national laboratories at our June meeting. We look forward to continuing our ongoing review of DOE's technical activities related to management and disposal of SNF and high-level radioactive waste.

Sincerely,

Rodney C. Ewing

Rodney C. Ewing
Chairman

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Department of Energy
Washington, DC 20585

January 27, 2016

Dr. Rodney C. Ewing
Chairman
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

Dear Dr. Ewing,

Thank you for your letter regarding the Nuclear Waste Technical Review Board 2015 Summer Meeting in Golden, Colorado. The Department of Energy (DOE) appreciates your observations and recommendations related to the transportation of commercial spent nuclear fuel, and appreciated the opportunity for several DOE team members to participate in the meeting.

The Department is committed to developing a robust capability to transport spent nuclear fuel in a safe and effective manner to support a future integrated waste management system. As we continue to evaluate technical issues associated with transporting commercial spent nuclear fuel, we will take into account the Board's recommendations that the Department:

- collaborate with the utilities and the Nuclear Regulatory Commission to identify and resolve issues that could affect the ability to transport spent nuclear fuel in current canisters and casks;
- assume a greater role in integrating R&D being performed on dry-storage canisters, as well as the identification and communication of technical information on storage, transportation, and repackaging; and
- continue its work exploring the costs and potential benefits of implementing a standardized transportation, aging, and disposal canister.

Consistent with the Board's recommendation on publishing documentation supporting the Department's integration and planning tools, we recently held a demonstration of our System Analysis and Crosscut Tools that are currently under development. We were very pleased that two members of the Board were able to participate in this demonstration. As discussed at the demonstration, we are working to increase public access to elements of the Department's data, reports, and integration and planning tools. We hope the demonstration provided the Board with an overview of how each of the tools fit together to deliver a robust system to support decision-making. We invite any interested Board members to request access to CURIE on curie.ornl.gov, which serves as our public-facing information exchange.

The Board noted in its observations and recommendations that the time available to discuss chloride induced stress corrosion cracking (CISCC) of dry canisters was insufficient at the meeting. We invite the Board to reach out to the DOE team requesting more information or to schedule further time to discuss the issue at the Board's convenience.

We look forward to further engagement with the Board on these extremely important issues in the future.

Sincerely,

John F. Kotek
Acting Assistant Secretary
for Nuclear Energy

Department of Energy
Washington, DC 20585

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June 9, 2016

Rodney C. Ewing, Ph.D.
Chairman
U.S. Nuclear Waste Technical Review Board
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Suite 1300
Arlington, VA 22201

Dear Dr. Ewing:

The Department of Energy (Department) appreciates our meeting with you and staff of the U.S. Nuclear Waste Technical Review Board (the Board) to discuss the recent report, *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program*. The Department has carefully reviewed the report to understand the insights and conclusions.

I'm pleased to report that many of the Board's suggestions have already been included in the plans for the Deep Borehole Field Test (DBFT), a program designed to evaluate the technical and programmatic feasibility of the deep borehole disposal concept. A general response to the Board's report is presented in the context of the DBFT as Enclosure 1. The Board's report identified four findings and made nine specific recommendations; our detailed responses to these are included in Enclosure 2. I should note that we find the report potentially misleading and open to interpretation regarding our plans for the DBFT. I should also note that while many of the experts expressed their opinions regarding borehole disposal at the workshop, few made the clear distinction between what was appropriate for the DBFT (which does not involve radioactive waste) and an actual waste disposal facility based on the borehole concept. We are incorporating into our plans the Board recommendations that are consistent with both the research focus of the DBFT and DOE's budget and schedule considerations that constrain the DBFT.

The Department recognizes that there is much work to do to bring about disposal of high-level radioactive waste and spent nuclear fuel, and we acknowledge the Board's many contributions in helping us to evaluate various disposal concepts, including the deep borehole. If you have any question about our responses, please contact Andrew Griffith at (202) 586-3715.

Respectfully,

John F. Kotek
Acting Assistant Secretary
for Nuclear Energy

Enclosures

Enclosure 1

DOE's Summarized Response to the NWTRB Report on the DOE Deep Borehole Disposal Research and Development Program

The overall objective of the Deep Borehole Field Test (DBFT) is to demonstrate and evaluate technologies necessary for determining the feasibility and safety of deep borehole disposal for practical and safe disposal of smaller DOE-managed waste forms. In October 2015, at the Nuclear Waste Technical Review Board (NWTRB) International Technical Workshop on Deep Borehole Disposal of Radioactive Waste, and in prior DOE reports and presentations, DOE described planned DBFT activities to achieve this overall objective (see the References section at the end of this summary). These activities are for the most part consistent with those recommended by the NWTRB in their recent report, *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program*, January 2016. The DBFT is not intended to characterize a specific location as a potential disposal site. DOE will limit the scope of its research and demonstration activities and DBFT data collection to what is needed to evaluate the technical feasibility of the deep borehole disposal concept.

The DBFT scope is focused on achieving the following field test objectives (MacKinnon, 2015 and Sassani and Hardin, 2015):

1. Obtain a suitable test site
2. Design, drill and construct the Characterization Borehole (CB) to requirements
3. Collect data in the CB on geological, geomechanical, geochemical, and hydrologic conditions in the crystalline basement
4. Design, drill and construct the Field Test Borehole (FTB) to requirements
5. Design, develop, and demonstrate surface handling and emplacement equipment systems, test packages, and operational methods for safe canister/ package handling and emplacement with analyses of associated risks
6. Conduct generic post-closure safety analyses, utilizing DBFT data sets
7. Evaluate the feasibility and safety of the deep borehole disposal concept for disposal of smaller DOE-managed waste forms

These objectives will be accomplished by a DBFT team of recognized US and international experts with extensive experience in drilling, down-hole operations and testing, site characterization, safety assessment, and project management. This team includes the DBFT Contractor Team (Battelle Memorial Institute, Schlumberger, Solexperts AG), DOE, and technical experts from DOE National Laboratories (SNL, LANL, LBNL, ORNL, PNNL). A Technical Advisory Committee (TAC) will be established to monitor field test activities, especially during drilling and testing, and ensure the necessary data and information is collected. The membership of the TAC shall include key members of the DBFT team, and/or other external experts as necessary. *DOE does not believe, as recommended by the NWTRB, that it is necessary to have an additional group of experts review the drilling program design and implementation, nor is it necessary for an independent group to report on the field test to the Secretary of Energy.*

Descriptions of how each of these objectives will be accomplished are summarized below. Contrasts between the DBFT and actual disposal activities are included in the following

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summary along with remarks (noted in italics) related to recommendations made by the NWTRB.

Field Test Objective 1: Obtain a suitable test site

A number of geological, hydrogeological, and geophysical characteristics have been evaluated that are relevant to successfully completing the DBFT, and are derived from those delineated for post-closure safety for a deep borehole disposal system. This evaluation has produced guidelines for selecting a suitable site based on existing geologic information (see Arnold et al., 2014 and Sassani and Perry, 2015). These guidelines were developed with the primary goal of identifying potential favorable sites that appear to have a crystalline basement geology relatively isolated from the associated subsurface hydrogeologic system and biosphere. DBFT site selection will be based on existing geologic information and an evaluation of how well the site meets the guidelines. *In addition, DOE has concluded that for the specific purposes of the DBFT, the likely value of information gained at depths of 3-5 km from surface-based techniques does not warrant the expense of surface-based geophysical investigations at the scale the NWTRB envisions or recommends.* The need for and use of geophysical investigations in the context of the DBFT and deep borehole disposal are discussed further in the following paragraph.

Note that the DBFT has the objective of specifically addressing key data necessary to evaluate the feasibility of the deep borehole disposal concept, particularly unproven or especially critical components (e.g., collecting diagnostic geochemical and environmental tracer profiles from deep low-permeability crystalline rocks – See Field Test Objective 3), but does not address broader objectives that would be required for site characterization supporting actual implementation of a deep borehole disposal facility. For example, selection of a site suitable for an actual disposal facility would potentially involve site characterization investigations prior to drilling (e.g., surface-based and/or airborne geophysical surveys), but a decision to conduct such investigations would depend on the geologic information already available (e.g., indications of through-going faults or fracture zones), on the disposal safety case for that site, and on the needs of particular stakeholders.

To summarize, the DBFT will include sampling and testing of formations in the crystalline basement to detect and characterize discontinuities that intersect the borehole if they are present. However, surface-based geophysics, multi-borehole studies, and extensive downhole testing to characterize larger-scale, distal discontinuities that may be present, are not planned. If data from the crystalline basement hydrogeologic system (see Field Test Objective 3) indicate that it has direct/active connection to shallow meteoric groundwater aquifers and/or the biosphere, then additional activities could focus on identifying the transport pathway. For a potential disposal site, identification and characterization of potentially significant transport pathways could be carried out using conventional approaches such as: additional boreholes; surface, downhole, and cross-hole geophysical techniques; and borehole tracer and pressure tests. *DOE does not currently plan to use the characterization and field test boreholes to conduct cross-hole monitoring to provide information on the characteristics of the rock volume surrounding the boreholes*. However, if the deep borehole disposal concept is determined to be feasible, DOE may choose to conduct such a study in the future.

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Field Test Objective 2: Design, drill and construct the Characterization Borehole to requirements

This objective is to demonstrate, using existing technology, that a borehole having a bottom-hole diameter of 8.5 inches, with a specified maximum deviation, can be drilled to a depth of 5 km (with the last ~ 3 km in the basement), cased, and cemented to requirements. A preliminary design for the CB has been developed and documented (Kuhlman et al., 2015). Kuhlman et al. (2015) focuses on the conceptual design requirements of the DBFT, specifically the construction and completion of the CB and the FTB, as well as the characterization activities to be performed in the CB. The final design for the drilling and construction of the CB is being developed by a team including Battelle Memorial Institute, Schlumberger, Solexperts AG, DOE, and National Laboratory personnel and will be described in detail in the final Drilling and Test Plan (D&TP).

Field Test Objective 3: Collect data in the Characterization Borehole on geological, geomechanical, geochemical, and hydrologic conditions in the crystalline basement

The primary focus of this objective is to identify and evaluate key characteristics of the basement that are important to the safety of the concept and long-term waste isolation (MacKinnon, 2015 and Sassani and Hardin, 2015). *This objective is consistent with the NWTRB recommendation that the project team carefully consider the key parameters for the safety case that need to be measured during sampling and testing in the 2- to 5-km (1.2- to 3.1-mi) depth range encompassing the seal and disposal zones.* These characteristics include: ancient age of formation fluids that would indicate a system that has been isolated hydrologically from the biosphere (i.e., local, rock-dominated conditions) for millions of years; geochemically reducing conditions in the rock-brine system that would substantially inhibit mobilization of many important radionuclides; increasing brine density with depth that would act counter to any thermally-driven buoyancy flow that may enhance transport of radionuclides to the biosphere during the short-lived thermal period; and very low basement rock permeability. These key characteristics have been observed in previous studies of crystalline basement formations in the US, Canada, and Europe and are expected to exist at the suitable DBFT site. Data will be collected to evaluate:

- Deep groundwater in the crystalline basement to assess if it is very old, saline, dominated by rock reactions (i.e., rock equilibrated), and reduced/reducing;
- Formation fluid pressure, to check whether an ambient fluid potential gradient exists to drive flow from the deep disposal zone to the shallow subsurface (i.e., over-pressured conditions present at depth), or conversely, if under-pressured conditions exist in the crystalline basement hydrology (which would be favorable for isolation);
- Bulk permeability properties of the host rock and of the borehole disturbed rock zone (DRZ), if one exists, to assess disturbed transport properties (i.e., permeability at the borehole scale, rather than the core scale); and
- Uncertainty and variability in data, to assess data transferability and to support site-specific numerical models of waste isolation performance (i.e., geochemical, thermal, geomechanical, geohydrological properties and constitutive laws) and post-closure safety.

The types of data and the technologies needed to collect them (as the borehole is being drilled and after borehole completion) have been identified and described by Kuhlman et al. (2015). The types of data to be collected as a function of depth will focus on providing data *for key parameters for the safety case* and include:

- Crystalline basement faults and fractures near the borehole
- Lithology and stratigraphy
- Physical and transport parameters
- Geochemical parameters
    - Fluid composition
    - Stable isotope ratios (e.g., ^{2}H, ^{18}O)
    - Uranium decay series isotope ratios
    - Strontium isotope ratios
- Geomechanical parameters
- Environmental tracer transport parameters

The subsurface geology and variable in situ conditions at depth will be developed from existing data and from new characterization data from the DBFT, and will be organized and synthesized in the form of a three-dimensional site geologic framework model. This model will include heterogeneity and variability in geologic properties consistent with the collected and available information and will provide data transparency and facilitate data access. Key geologic inputs for the geologic framework model include the stratigraphy and any known structures of the selected area, with a focus on the depth to the crystalline basement, mineralogy and rock fabric/texture, identified aquifers and permeable zones, stress regime, physical rock properties, and the scale of heterogeneity within rock units. *The data will be used to provide key inputs for post-closure safety assessment modeling efforts and to address technical and scientific issues related to the potential heterogeneity of the subsurface geology and complex in situ conditions a depth.*

As summarized above, the focus of DOE's field test will be to collect data and conduct analyses that are in large part consistent with that recommended by the NWTRB. However, again it is emphasized that DOE will limit the scope of its DBFT data collection to that needed to evaluate the feasibility of the deep borehole disposal concept, which is a lesser scope than would be needed to fully characterize a disposal site.

Field Test Objective 4: Design, drill and construct the Field Test Borehole to requirements

The primary goal of this objective is to evaluate whether, using existing technology, a borehole having a bottom-hole diameter of 17 inches, with specified maximum deviation and dogleg severity, can be drilled to a depth of 5 km (with the last ~ 3 km in the basement), and completed to requirements that allow safe emplacement of surrogate waste packages to depths between 3 and 5 km. A preliminary design for the FTB has been developed and documented (Kuhlman et al., 2015). The process for developing the final design and the drilling and test plan (D&TP) for the FTB will use experts from contractors, National Laboratories, and DOE similar to that described above for the CB.

Limited subsurface characterization is planned for the FTB, and planned characterization will focus on evaluating the quality of the FTB construction. Note that in an actual disposal facility some downhole characterization might be included depending on the distance from other boreholes, and geologic characteristics of the site. *In addition, DOE does not currently plan to conduct on-going subsurface monitoring in the FTB after emplacement testing, as was* *recommended by the NWTRB, primarily because of the limited value of information that could be collected within the time frame of the DBFT as currently planned.* However, if the deep borehole disposal concept is determined to be feasible and the FTB is not closed at the end of the DBFT, DOE may choose to conduct a monitoring study in the future.

Field Test Objective 5: Design, develop, and demonstrate surface handling and emplacement equipment systems, test packages, and operational methods for safe canister/package handling and emplacement with analyses of associated risks

The scope of this objective is to design, build, and operate a system that represents what could be used for an actual disposal system and radiological operations involving radioactive waste. The extent of this system and the field test is limited to evaluating and demonstrating system elements and safe handling operations that are unique to deep borehole disposal, such those involving the interface between cask unloading, borehole emplacement of test packages, and retrieval of test packages. Wireline emplacement of test packages will be demonstrated in the field test. This mode of emplacement was selected based on the evaluation of cost and risk described in SNL (2015). An evaluation of this work is documented in a report by AREVA (2016). DOE will develop a description of the handling operations and system elements that will be utilized in the DBFT prior to implementation. *Risk analyses will be conducted for handling and emplacement operations and important potential accident scenarios, but these analyses will be limited to operations unique to deep borehole disposal and wireline emplacement. DOE does not plan to conduct a comprehensive assessment of other modes of emplacement as recommended by the NWTRB but may consider doing such assessments in the future if the concept of deep borehole disposal is determined to be feasible.* Safe handling of nuclear materials under a variety of handling and transportation conditions is a well-developed discipline and DOE and its interdisciplinary team have high confidence that safe engineering solutions for a complete transportation, surface handling, and emplacement system can be developed if the deep borehole disposal concept is determined to be feasible and DOE decides to pursue disposal of DOE-managed waste forms in deep boreholes. DOE does plan to develop a description of upstream system components and operations for smaller DOE-managed waste forms (Price et al., 2015).

To support the design of a seal system for potential future disposal boreholes, the DBFT will include laboratory studies to evaluate sealing materials at representative temperature, pressure, salinity, and geochemical conditions. *The current field test plan does not include field testing of borehole seals or sealing methods as recommended by the NWTRB. However, DOE will consider such testing if it is determined that field testing is required to complete the evaluation of feasibility. This determination and the design of field testing will require data and analysis and therefore borehole sealing materials and emplacement configurations will be examined in parallel with DBFT field operations, starting from the reference seal design in Arnold et al. (2011) and Hardin (2015).*

Key components of the DBFT seals effort will include:

- Review of borehole seal practices in other borehole-related disciplines such as CO2 sequestration, deep well injection of hazardous wastes, and oil and gas production
- Development of sealing requirements and seal emplacement methods
- Experimental analysis of bentonite alteration and steel corrosion under borehole conditions

- Evaluation of seal-DRZ interface properties for conventional sealing materials
- Consideration of new sealing approaches including novel cements and thermite plugs
- Laboratory verification of rock weld properties

Eventually, the DBFT boreholes may be made available to the scientific and engineering R&D community as a deep borehole underground laboratory. *If the deep borehole disposal concept is determined to be feasible, in situ tests of seal emplacement and performance can be conducted when planned DBFT activities have concluded.*

Field Test Objective 6: Conduct post-closure safety analyses

The post-closure safety case for deep borehole disposal relies primarily on the long-term isolation of the deep geologic environment of the crystalline basement. A key element of the safety case is the demonstration that deep groundwater is very old and has been isolated from the surface or near-surface for very long periods of time (on the order of 10^6 years or longer). The DBFT will evaluate deep groundwater age from geochemical indicators such as salinity, and from isotopic indicators using environmental tracers such as noble gases. High salinity at depth also indicates old groundwater and precludes use of deep groundwater as a drinking water source. Increasing salinity with depth promotes stable stratification based on fluid density, and tends to oppose upward thermal convection from waste heat. Absence of over-pressured conditions at depth is expected at favorable locations for deep borehole disposal. The bulk permeability of deep crystalline rocks is generally very low and decreases with depth. The effectiveness and durability of borehole seals through the period of upward thermal convection are also elements of the safety case and are addressed through a borehole disposal concept that includes multiple barrier seal materials in the borehole above the waste disposal zone. *The post-closure safety case does not rely on waste form and waste package performance because of the isolation capabilities of the deep geologic environment of the crystalline basement.*

Post-closure safety of the deep borehole disposal concept will be evaluated with a comprehensive three-dimensional probabilistic post-closure safety assessment model using the geologic framework model and characterization data developed under Field Test Objective 3. A Features, Event, and Process (FEP) screening approach (Freeze, 2015) will be conducted to determine those FEPs that will be included in the safety assessment model. *DOE does plan to adequately assess coupled processes and the impact of drilling on the natural geologic system, and this FEPs screening process will include evaluation of coupled processes, system heterogeneities, and the impact of drilling on the natural geologic system.* A suite of safety analyses will be conducted to evaluate the long-term performance of a hypothetical deep borehole disposal facility having a geologic system consistent with the DBFT site. Smaller DOE-managed waste forms will be considered as candidate waste forms for disposal. *Alternative scenarios will be considered for accidents such as stuck and abandoned waste packages and geologic conditions that include possible enhanced/additional transport pathways in crystalline basement discontinuities such as fractures and faults. In addition, , if the deep borehole disposal concept is found to be feasible the DOE may evaluate the potential safety benefits of robust waste forms and waste packages in its suite of planned safety analyses.*

<u>Field Test Objective 7: Evaluate the feasibility and safety of the deep borehole disposal concept</u>

This objective will be achieved by synthesizing field test activities, test results, and safety analyses into a comprehensive evaluation of concept feasibility. Data and experience that will be evaluated include data gathered during site characterization, experience gathered during drilling and borehole construction, data gathered during physical demonstration of surface handling and borehole emplacement and retrieval operations, pre-closure safety analyses, and post-closure safety analyses.

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Enclosure 2

DOE Responses to the NWTRB's Specific Findings and Recommendations

Findings

Even if disposal of some radioactive waste in deep boreholes is determined to be feasible, the need for a mined, geologic repository is not eliminated.

The Board's finding supports DOE's position that a mined geologic repository will be required even if deep borehole disposal is implemented. (No additional action)

Establishing a regulatory framework, identifying an acceptable site, and characterizing a deep borehole at depths down to 5 km (3.1 mi) are challenging and time consuming activities, suggesting that the time required for completing a deep borehole disposal facility might be comparable to that of a mined, geologic repository.

The Board's finding identifies some of the unknown factors regarding the deep borehole concept, including schedule uncertainty. The DBFT is limited to analyzing technical feasibility of the concept. (No additional action)

The Deep Borehole Field Test will provide only limited information on which to base an evaluation of the feasibility of the deep borehole disposal concept and the selection of a deep borehole disposal site.

The Deep Borehole Field Test (DBFT) is not intended to collect data to consider a specific site for disposal of radioactive waste. The DBFT should provide significant information to evaluate the engineering feasibility of the disposal concept and aspects of operational and post closure safety. The Department believes this information will inform a site selection process in much the same way the proven deep geologic repository concept informs the site selection process.

The operational implications and limitations of handling and emplacing highly radioactive waste at depth are very different from those for operations involving non-radioactive material; however, evaluating and understanding those implications and limitations are of utmost importance for the design of a deep borehole disposal facility and for the feasibility assessment of the deep borehole disposal concept.

The second phase of the DBFT will demonstrate surface handling and downhole emplacement of surrogate waste packages in the full-diameter field test borehole. This demonstration will be representative of actual operations needed for radioactive waste disposal. (No additional action)

Recommendations

Independent expert review—The Board recommends that DOE ensure the drilling program design and implementation are reviewed by experts with extensive experience in drilling and down-hole operations (e.g., logging, testing, well completion) and in designing and operating equipment for handling highly radioactive material. These experts should be independent of the Deep Borehole Field Test contractor and of the lead national laboratory on the project, and should be able to monitor the progress of the project and report on it to the Secretary of Energy.

> DOE's interdisciplinary team of contractors and national laboratories that will plan and conduct the field test are leading experts in project management, drilling subsurface characterization and testing, nuclear materials handling, and risk and safety assessment. The DOE team is fully capable of presenting to the DOE Secretary, independent experts, review committees, and stakeholders the status and findings of the deep borehole field test as it progresses through its planning and implementation.
>
> A Technical Advisory Committee (TAC) will be established to monitor field test activities, especially during drilling and testing, and ensure the necessary data and information is collected. The membership of the TAC shall include key members of the DBFT team, and/or other external experts as necessary. DOE does not believe, as recommended by the NWTRB, that it is necessary to have an additional group of experts review the drilling program design and implementation, nor is it necessary for an independent group to report on the field test to the Secretary of Energy. (No additional action)

Comprehensive risk analysis—The Board recommends that a more comprehensive risk analysis be completed for all aspects of the drilling and emplacement program as part of assessing the feasibility of deep borehole disposal of radioactive waste. In particular, an analysis should be conducted of what options will be available in the event of an accident during waste emplacement and the implications of such an accident for the safety of recovery operations and the isolation of waste. A transparent and comprehensive assessment of the five possible emplacement modes for deep borehole disposal, including their absolute and relative risks for having and recovering from an accident, also should be completed.

> The Department plans to conduct risk analyses for handling and emplacement operations and important potential accident scenarios, but these analyses will be limited to handling operations unique to deep borehole disposal and wireline emplacement. The Department does not plan to conduct a comprehensive assessment of all other modes of emplacement as recommended by the NWTRB, but may consider doing such assessments in the future if the concept of deep borehole disposal is determined to be feasible. (No additional action)

Heterogeneity of subsurface geology and transferability of data and results of analysis—The Board recommends that DOE strengthen its assessment of the feasibility of the deep borehole disposal option by addressing the technical and scientific issues related to the

potential heterogeneity of the subsurface geology and the complex *in situ* conditions at depth. DOE should take into consideration the potential implications, with a focus on conducting a defensible safety analysis and demonstrating the transferability of the data and results of analysis to other sites. DOE should address these issues in the guidance it provides to the contractor for developing the drilling and test plan. Specifically, the project team should carefully consider the key parameters for the safety case that need to be measured during sampling and testing in the 2- to 5-km (1.2- to 3.1-mi) depth range encompassing the seal and disposal zones. For example, DOE should identify down-hole logs, tests, and monitoring techniques that could lead to a better understanding for the potential development of a free gas phase (*e.g.*, hydrogen from the rapid corrosion of steel components) and its implications for disposal system behavior. The goal for characterization should be obtaining relatively continuous down-hole profiles based on multiple measurements, rather than relying on, and interpolating between, a limited set of measurements. DOE also should consider using the characterization and field test boreholes to conduct cross-hole monitoring to provide information on the characteristics of the rock volume surrounding the boreholes. Moreover, on-going subsurface monitoring after the emplacement testing, to continue to test and evaluate starting assumptions, should be included in the drilling and test plan.**

> The Department agrees with the Board that these are topics that need to be considered in developing the drilling and test plan (D&TP); the DOE also agrees with the Board's observation that subsurface geology is heterogeneous and site-specific geologic information obtained during the DBFT will have limited transferability to other locations. Future disposal boreholes, if any, will need individual characterization. The Department believes that the DBFT will provide valuable information about the feasibility of the disposal concept in a generic sense in multiple ways: e.g., by informing preliminary site screening criteria, by demonstrating construction of boreholes to requirements, by providing the opportunity to evaluate down-hole characterization techniques, and by providing a test of operational engineering techniques. (No additional action)

Pre-drilling geophysical subsurface characterization—The Board recommends that the Deep Borehole Field Test include surface-based geophysical surveys to delineate subsurface structure and physical conditions prior to drilling (*e.g.*, detailed gravity, magnetic, seismic, or electrical data). These measurements could help in the design of the Deep Borehole Field Test drilling and test plan and provide knowledge for using surface-based measurements to evaluate the subsurface characteristics of potential deep borehole sites prior to drilling.

> The Department appreciates the Board's suggestion for surface-based geophysical characterization prior to drilling, and intends to use available information. However, the Department has concluded that for the specific purposes of the DBFT, the value of information gained at depths of 3-5 km from surface-based techniques is unlikely to warrant the expense of surface-based geophysical investigations at the scale the Board envisions. (No action)

Robust waste forms, waste packages, and seals—The Board recommends that DOE explicitly analyze the potential safety benefits of using more robust waste forms and waste packages as part of assessing the feasibility of the deep borehole disposal concept and in developing the associated safety case. The Board also recommends that the Deep Borehole

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Field Test be used to demonstrate emplacement of potential seals and to test the efficacy of seal materials in dealing with breakouts and evolving damage zones around the borehole when exposed to *in situ* thermal, hydrogeologic, geomechanical, microbiological, and chemical conditions. Geophysical techniques (*e.g.*, acoustic sonic and ultrasonic tools) should be used to verify the seals between the casing and rock where the casing remains in the borehole.

> If deep borehole disposal is found to be feasible, the DOE may evaluate the potential safety benefits of robust waste forms and waste packages in follow-on studies. DOE does plan to investigate the behavior of different seal materials in the laboratory under representative downhole temperature, pressure, and chemical conditions to inform our effort to design a seal system. This information will be used to evaluate opportunities for in-situ testing of sealing technologies during the course of the DBFT, however, sealing experiments are generally incompatible with future non-nuclear R&D uses of the hole. (No additional action)

Developing an operational safety strategy—The Board recommends that DOE develop an operational safety strategy for the Deep Borehole Field Test that integrates conventional borehole operations and remote handling of highly radioactive materials. This might include emphasizing the use of engineering controls (*e.g.*, automated equipment to protect workers) over administrative controls (*i.e.*, processes that rely on personnel actions and procedures). The Deep Borehole Field Test should simulate implementation of deep borehole disposal as if radioactive wastes were being emplaced in order to test the features of an operational safety strategy that can be applied to a future borehole disposal site and to provide the basis for ensuring safe operations, limiting exposure of workers to hazards or release of radioactive material to the environment, and mitigating waste emplacement risks.

> The Department plan incorporates the Board's recommendation. The Department plans to design, build, and operate a system that represents what could be used for an actual disposal system and radiological operations involving radioactive waste. This system and operations will be demonstrated at the 2nd field test borehole (FTB). Demonstration activities will be limited to evaluating and demonstrating system elements and safe handling operations that are unique to deep borehole disposal, such those involving the interface between cask unloading, borehole emplacement of surrogate test packages, and retrieval of test packages. (No additional action)

Engaging regulators to define retrievability requirements—The Board recommends that, as part of its assessment of the feasibility of deep borehole disposal of radioactive waste, DOE place a high priority on engaging regulators to define retrievability requirements in the context of deep borehole disposal of radioactive waste. DOE should begin defining and clarifying the types of technical information that may be needed to address regulatory issues and then collect that information to the extent practicable as part of the Deep Borehole Field Test.

The Department agrees that regulatory clarity is necessary before any decisions can be made regarding deep borehole disposal of radioactive wastes and will incorporate interactions with the regulators into the project schedule as appropriate. (Pending)

A transparent pathway from the Deep Borehole Field Test to siting—The Board recommends that DOE use the Deep Borehole Field Test to gain experience related to its siting approach. DOE should begin to incorporate new standards of transparency and data access, and should explore avenues to engage stakeholders.

The Department has initiated a process to obtain public feedback to help design a consent-based process. The process will be used to site future nuclear waste facilities - which could include a deep borehole. The consent-based process will be transparent, phased and adaptive. (No additional action)

Chief scientist in charge of the Deep Borehole Field Test program—The Board recommends that the DOE Deep Borehole Field Test program have a chief scientist responsible for integrating the engineering activities (i.e., drilling the characterization and field test boreholes, emplacing and retrieving the simulated waste) and the site characterization activities. The chief scientist should have the scientific understanding required to ensure the technical integrity of information gathered in the Deep Borehole Field Test and its use for developing the safety case for deep borehole disposal of radioactive waste.

In lieu of a chief scientist as envisioned by the Board, the Department will establish a Technical Advisory Committee (TAC) to monitor field test activities. The membership of the TAC includes members of the DBFT Contractor team (Battelle Memorial Institute, Schlumberger, Solexperts AG), DOE, technical experts from DOE National Laboratories (Sandia National Laboratories, Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory), and/or other external experts as necessary. (No additional action)

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July 7, 2016

Mr. John Kotek
Acting Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Re: DOE Response to Board Report titled *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program.*

Dear Mr. Kotek:

Thank you for your letter dated June 9, 2016, that presents DOE's responses to the findings, conclusions, and recommendations presented in the Board's report on its technical evaluation of the DOE deep borehole disposal research and development program.

While the Board recognizes that budget and schedule limitations will necessarily constrain the scope of the Deep Borehole Field Test program (DBFT), the Board remains concerned that the DBFT be designed to take advantage of the opportunity to develop a solid technical and operational basis for deep borehole disposal.

The Board looks forward to reviewing the draft drilling and test plan for the DBFT. I would be grateful if you would provide a copy of the draft plan for the Board to review as soon as it is available.

Sincerely,

Rodney C. Ewing
Chairman

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