U. S. Nuclear Waste Technical Review Board

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

Board Activities for the Period January 1, 2008 – December 31, 2012

U.S. Nuclear Waste Technical Review Board

A Report to the U.S. Congress and the Secretary of Energy

Board Activities for the Period

January 1, 2008 - December 31, 2012

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

December 2014

The Honorable John Boehner
Speaker
United States House of Representatives
Washington, DC 20515

The Honorable Patrick J. Leahy
President Pro Tempore
United States Senate
Washington, DC 20510

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

Dear Speaker Boehner, Senator Leahy, 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, 2008, through December 31, 2012.

The period covered by the Report was consequential for the U.S. program for managing and disposing of spent nuclear fuel and high-level radioactive waste and for the Board. The Board wishes to recognize the contributions of Dr. B. John Garrick, who was Board Chairman during the five years covered by the report, and whose leadership was an important factor in the Board's accomplishments during the period.

We hope that Congress and the Secretary will find the information in this archival summary report useful. The Board 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

EXECUTIVE STAFF

Nigel Mote	*Executive Director*
Debra L. Dickson	*Director of Administration*

SENIOR PROFESSIONAL STAFF

Bret W. Leslie	*Geoscience*
Daniel S. Metlay	*International, Social Science*
Daniel Ogg	*Nuclear Engineering, Operations*
Roberto T. Pabalan	*Geochemistry, Physical Chemistry*
Gene W. Rowe	*Nuclear Engineering, Operations*
Karyn D. Severson	*External Affairs*

ADMINISTRATIVE & SUPPORT STAFF

Jayson S. Bright	*Systems Administrator*
Davonya S. Barnes	*Information Systems Specialist*
Linda J. Coultry	*Program Management Specialist*

Executive Summary

The U.S. Nuclear Waste Technical Review Board was established by Congress in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) to undertake an independent and ongoing evaluation of the technical and scientific validity of U.S. Department of Energy (DOE) activities related to implementing the Nuclear Waste Policy Act (NWPA) of 1982. The Board's 11 members serve part time and are appointed by the President from a list of nominees submitted by the National Academy of Sciences. The Board reports its findings, conclusions, and recommendations to the U.S. Congress and the Secretary of Energy. This report summarizes the Board's activities for the period January 1, 2008, through December 31, 2012. All Board documents referred to in the report are available on the Board's website at www.nwtrb.gov. Board congressional testimony and correspondence for the period and other information on the Board can also be found in the appendices to this report.

The five years covered by the report were consequential for the U.S. program for managing and disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW). During that time, the direction of DOE's management and disposal activities changed significantly.

Background

In June 2008, DOE submitted a license application to the Nuclear Regulatory Commission (NRC) for authorization to construct a deep geologic repository at Yucca Mountain in Nevada, and NRC staff commenced a review of the license application.

Early in 2010, funding for the Yucca Mountain licensing effort and for DOE's Office of Civilian Radioactive Waste Management—the entity responsible for implementing DOE's obligations under the NWPA—was eliminated from DOE's budget and responsibilities for most of DOE's activities related to managing and disposing of commercial SNF were assigned to DOE's Office of Nuclear Energy. Also in early 2010, DOE filed a motion with NRC to withdraw the Yucca Mountain license application. Subsequently, several parties that had petitioned to intervene in the licensing hearing process, including the states of Washington and South Carolina and the County of Aiken in South Carolina, filed suit in the U.S. Court of Appeals for the District of Columbia Circuit to compel DOE and NRC to restart the licensing process. NRC's Construction Authorization Board denied DOE's motion to withdraw the license application in June 2010; however, the NRC Chairman at the time stopped all work on the license application by NRC staff in October 2010.

In January 2010, at the direction of the President, the Secretary of Energy created the Blue Ribbon Commission on America's Nuclear Future (BRC) to look at alternatives for managing "the back end of the nuclear fuel cycle." During 2010 and 2011, the BRC held numerous hearings and Board members and staff provided technical and scientific information to the

BRC on several occasions. The Board also commented on draft reports issued by the BRC's subcommittees and on the draft BRC report. In January 2012, the BRC issued its final *Report to the Secretary*. Among the BRC recommendations was the establishment of a consent-based process for siting a repository for permanent disposal of SNF and HLW and a consolidated facility for interim storage of the waste. The BRC also recommended the creation of a new implementing organization for the disposal of SNF and HLW. The Board provided comments to Secretary Chu on the final BRC report.

Board Response to Evolving SNF and HLW Program

As the focus of DOE's NWPA implementation activities transitioned from licensing a Yucca Mountain repository to identifying a new path forward for nuclear waste management, the Board continued to review the technical and scientific validity of DOE activities. The Board sent a letter to the Secretary of Energy in August 2009, in which the Board described its priorities during this period: (1) continue reviewing DOE's ongoing nuclear waste management activities; (2) provide technical findings and information to Congress, the Secretary of Energy, and the BRC that could be used in evaluating alternatives for managing nuclear waste; and (3) create information products that could be used to inform, from a technical perspective, the discussion of waste management alternatives.

The Board sent a letter report to Congress and the Secretary of Energy in October 2009, in which the Board articulated the direction and focus of its ongoing review of DOE activities, given changes that were anticipated in the DOE program. In particular, the Board clarified that its statutorily mandated technical evaluation of DOE activities related to implementing the NWPA would continue regardless of where in DOE the activities were undertaken.

Board Activities during the Period

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 to submit written reports to the U.S. Congress and the Secretary of Energy. During the period covered by this report, the Board published seven such reports, including the letter report discussed in the previous paragraph and the following:

- *U.S. Nuclear Waste Technical Review Board Report to the U.S. Congress and the Secretary of Energy March 1, 2006 - December 31, 2007 (September 2008)*
- *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel (October 2009)*
- *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel—Executive Summary (December 2010)*
- *Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries (April 2011)*
- *Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Wastes: Lessons Learned from Yucca Mountain and Other Programs (June 2011)*

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

Board Testimony—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 on two occasions to congressional committees.

Board Meetings and DOE Correspondence—During the reporting period, the Board held 15 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, which includes 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 last section of this report presents a discussion of significant technical and scientific issues that emerged from the Board's review of DOE's work during the period January 1, 2008, through December 31, 2012.

Interactions with the Interested Public—A fixture of all Board meetings is the public comment session, where members of the interested public are invited to comment and ask questions regarding 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 Board's meetings provide 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 comments and other materials submitted by public commenters are included in the meeting records on the Board's website: www.nwtrb.gov.

Interactions with Other SNF and HLW Programs—Since its inception, the Board has interacted in various ways with SNF and HLW 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 to enhance the Board's technical and scientific evaluation of DOE activities. During the period covered by this report, small delegations of Board members and staff visited SNF management programs in several countries. The Board also involved representatives of programs in other countries as presenters at several of the Board's public meetings.

Contents

The Board and Its Mission 1

Developments Related to Nuclear Waste Management 1

Board Response to Evolving SNF and HLW Program 2

Board Activities: January 1, 2008 - December 31, 2012 3

Board Reports 3

Board Testimony before Congress 5

Board Interactions with the BRC 6

Board Interactions with the Interested Public and with Radioactive Waste Management Programs in Other Countries 10

Board Review of DOE Activities Related to Implementing the NWPA – Significant Issues 11

Yucca Mountain 12

Generic Investigations and Analyses 15

SNF and HLW Storage and Transportation 18

Nuclear Fuel Cycle 19

Disposal and Management of DOE SNF and HLW 19

Future Plans 21

Abbreviations and Acronyms 23

Contents Continued

Glossary of Terms 25

References 33

Appendices. 39

A. Board Members

B. Board Strategic Plan

C. Board Publications

D. Board Testimony

E. Board Presenations and Letters to the BRC

F. Meetings of the Board

G. Board Correspondence with DOE

The Board and Its Mission

The U.S. Nuclear Waste Technical Review Board (NWTRB) was established by Congress in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) to undertake an independent and ongoing evaluation of the technical and scientific validity of U.S. Department of Energy (DOE) activities related to implementing the Nuclear Waste Policy Act (NWPA) of 1982. The 1987 Act also designated Yucca Mountain in Nevada as the sole site to be characterized by DOE for its suitability as the location of a deep geologic repository for the disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW). The Board is charged with reporting its findings, conclusions, and recommendations to Congress and the Secretary of Energy. This report summarizes the Board's activities for the period January 1, 2008, through December 31, 2012. All Board documents referred to in the report are available on the Board's website at www.nwtrb.gov. Board congressional testimony and correspondence for the period and other information on the Board can also be found in the appendices to this report.

The Board's 11 members serve part time and are appointed by the President from a list of nominees submitted by the National Academy of Sciences. Board members are nominated solely based on established records of expertise and eminence in technical and scientific disciplines relevant to work performed by DOE in implementing the NWPA. During the period covered by this report, the following former members served on the Board: B. John Garrick, Ph.D., Chairman; Mark D. Abkowitz, Ph.D.; Thure E. Cerling, Ph.D.; George M. Hornberger, Ph.D.; Ronald M. Latanision, Ph.D.; William M. Murphy, Ph.D.; William Howard Arnold, Ph.D., P.E.; David J. Duquette, Ph.D.; Andrew C. Kadak, Ph.D.; Ali Mosleh, Ph.D.; and Henry Petroski, Ph.D., P.E.[1]

All of the current Board members were appointed to the Board by President Barack Obama. Three of the current Board members—Sue B. Clark, Ph.D.; Rodney C. Ewing, Ph.D.; and Linda K. Nozick, Ph.D.—were appointed in July 2011, and eight more members—Jean M. Bahr, Ph.D.; Steven M. Becker, Ph.D.; Susan L. Brantley, Ph.D.; Efi Foufoula-Georgiou, Ph.D.; Gerald S. Frankel, Sc.D.; Kenneth Lee Peddicord, Ph.D., P.E.; Paul J. Turinsky, Ph.D.; and Mary Lou Zoback, Ph.D.—were appointed in September 2012. Also in September 2012, Dr. Rodney C. Ewing was designated by the President to serve as Board Chairman. Biographies of the current Board members are included in Appendix A.

Developments Related to Nuclear Waste Management

The five years covered by this report were consequential for nuclear waste management and disposal efforts in the U.S. In June 2008, following some 20 years of technical, scientific, and operational analyses and investigations, DOE submitted a license application to the U.S. Nuclear Regulatory Commission (NRC) for authorization to construct a Yucca Mountain repository, and NRC staff commenced a review of the license application. Then, as discussed below, in 2010, the Administration of President Barack Obama undertook several major actions that signaled a significant change in approach to SNF and HLW management and disposal.

[1] Full biographies of members of the Board who served during the period covered by this report can be found in the Board's Report to the U.S. Congress and the Secretary of Energy, issued in September 2008. The report is available on the Board's website at www.nwtrb.gov.

In February 2010, the Administration submitted a budget to Congress that included zero funding in fiscal year 2011 for DOE's Office of Civilian Radioactive Waste Management (OCRWM). OCRWM was the entity that had until that time been responsible for implementing DOE's responsibilities—established in the NWPA—for managing and disposing of SNF and disposing of HLW. At this point, OCRWM's responsibilities under the NWPA transitioned primarily to DOE's Office of Nuclear Energy, while the DOE Office of Environmental Management retained responsibility for environmental cleanup of DOE sites and acquired responsibility for managing the shutdown of the Yucca Mountain site in Nevada. DOE's Office of Legacy Management was given responsibility for preserving data and documents associated with the Yucca Mountain repository program.

DOE petitioned NRC in early 2010 for permission to withdraw the license application for Yucca Mountain. At about the same time, some of the parties that had petitioned to intervene in the licensing hearing process, including the states of Washington and South Carolina and the County of Aiken in South Carolina, filed suit in the U.S. Court of Appeals for the District of Columbia Circuit to prevent DOE's withdrawal of the license application. In June 2010, NRC's Construction Authorization Board denied DOE's request, but in October 2010, NRC Chairman Gregory Jaczko directed NRC staff to cease its technical review of the Yucca Mountain license application.

In January 2010, at the direction of the President, Energy Secretary Steven Chu established the Blue Ribbon Commission on America's Nuclear Future (BRC) to evaluate options for managing the back end of the nuclear fuel cycle. Throughout 2010 and 2011, the BRC continued its deliberations and held numerous hearings, at which stakeholders and members of the public were given the opportunity to present their points of view on managing nuclear wastes. The BRC issued its final report and recommendations in January 2012. The BRC recommendations included the establishment of a consent-based process for siting a repository for permanent disposal of SNF and HLW and a consolidated facility for interim storage of the waste. The BRC also recommended the creation of a new implementing organization for the disposal of SNF and HLW.

Board Response to Evolving SNF and HLW Program

As DOE's activities related to implementing the NWPA transitioned from licensing the Yucca Mountain repository to identifying a new path forward for nuclear waste management, the Board continued its statutorily mandated technical and scientific review of DOE activities. The Board also expanded its efforts to develop technical and scientific information and insights from the experiences of nuclear waste disposal programs in the U.S. and other countries that could be used to advise decision-makers in Congress and the Administration.

In June 2009, the Board wrote to Congress and Secretary Chu (Garrick 2009b), expressing Board support for the Secretary's decision (at the time) to continue the licensing process for a Yucca Mountain repository. The Board noted that this decision "allows a full adjudication of the technical issues and allows all the parties to the process, including the state of Nevada, to identify and support their contentions so that the maximum scientific and engineering benefit can be derived from the effort."

In an August 2009 letter to Secretary Chu (Garrick 2009c), the Board identified three objectives that would guide its ongoing review of DOE activities:

> 1. To the extent that DOE engaged in technical work related to the management and disposal of SNF and HLW, the Board would continue to monitor and evaluate that work and report on the technical validity of the work to Congress and the Secretary.
>
> 2. The Board would continue developing and compiling objective technical information to inform Congress, the Secretary of Energy, and a blue ribbon commission, should one be established. In developing such information, the Board would look broadly at an integrated waste management system and potential waste management alternatives and provide its objective view of technical questions and issues needing to be addressed.
>
> 3. The Board would draw on its extensive experience, including knowledge gained from observing efforts in other countries, to develop and provide technical and scientific information and "lessons learned" about the U.S. nuclear waste management program, including the operational and safety risks of alternatives for managing high-level radioactive waste.

The Board sent a letter report to Congress and the Secretary of Energy in October 2009 (Garrick 2009d), in which the Board articulated the direction and focus of its ongoing review of DOE activities, given changes that were anticipated in the DOE program. In particular, the Board clarified that its statutorily mandated technical review of DOE activities related to implementing the NWPA would continue regardless of where in DOE the activities were undertaken. The Board also identified relevant technical and scientific topics on which information would be developed that would help inform decision-makers in the Administration and Congress.

In September 2010, the Board issued its Strategic Plan for fiscal years 2011 to 2016. The updated Plan clarified the Board's continuing peer-review mandate, its strategic goals and objectives, and its vision for making an ongoing contribution to the technical and scientific validity of activities and decisions related to nuclear waste management and disposal.[2] The Board's primary objectives for the period were focused on its review of DOE activities and on providing technical and scientific information to decision-makers in Congress, DOE, and the Administration. The Board also placed a very high priority on interacting with and providing access for the public to its technical and scientific reviews and information. The Board's Strategic Plan for fiscal years 2011 to 2016 can be found in Appendix B.

Board Activities: January 1, 2008 - December 31, 2012

Board Reports

One of the primary means used by the Board for communicating its official findings, conclusions, and recommendations is to send written reports to the U.S. Congress and the Secretary of Energy. During the period covered by this report, the Board published seven such reports, including the letter report discussed in the previous section and the six

[2] The Board's annual performance goals and evaluations are included in its annual budget submittals, which are available on the Board's website: www.nwtrb.gov.

reports summarized below. A chronological listing of Board publications is included in Appendix C.

In September 2008, the Board issued a *Report to the U.S. Congress and the Secretary of Energy* summarizing the Board's activities from March 1, 2006, through December 31, 2007. During the period covered by that report, the Board focused its evaluation of DOE activities on five critical technical issues dealing with the system for managing SNF and HLW and six critical technical issues dealing with the post-closure performance of the proposed Yucca Mountain repository. The Board also explored in depth the crosscutting issue of thermal management.

In October 2009, the Board published a report titled *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*. The report describes 30 technical and institutional attributes of nuclear waste programs in 13 countries. The purpose of the report was to provide up-to-date information to Congress, the Secretary of Energy, and other interested parties on the status of the various national programs for managing SNF and HLW. The report does not make judgments; rather, it provides factual information for Congress and the Secretary that can be used for evaluating waste management options.

The Board's report *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel—Executive Summary* was released in December 2010. The document summarizes and draws conclusions from a review of the literature undertaken by Board staff related to the challenges—including materials degradation—associated with very long-term dry storage of SNF at commercial nuclear power plants and the problems that might be encountered when the SNF is subsequently transported to a repository or consolidated storage facility.

The report *Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries* was issued by the Board in April 2011. This report built on information in the 2009 Survey Report and explored the efforts of 13 nations to find a permanent solution for isolating SNF and HLW generated within their borders. Unlike the earlier document, however, this report not only described the programs, it made observations drawn from the experiences of the 13 programs.

In June 2011, the Board released the report *Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Wastes: Lessons Learned from Yucca Mountain and Other Programs*. The purpose of this report was to gather and record knowledge, while it was still available, from experiences of the Yucca Mountain program and other management programs for SNF and HLW. In the report, the Board examined, from a technical and scientific perspective, the history of the Yucca Mountain program and other nuclear waste programs around the world, and discussed technical and scientific information and insights that could be useful for future SNF and HLW management and disposal efforts in the U.S.

In 2010, the Board began developing an analytical tool called the Nuclear Waste Assessment System for Technical Evaluation (NUWASTE) for analyzing options for managing the back end of the nuclear fuel cycle. Of particular interest to the Board were the types and quantities of the radioactive waste streams that would be generated by the different options. In June 2011, the Board issued the report *Nuclear Waste Assessment*

System for Technical Evaluation (NUWASTE): Status and Initial Results. In addition, the Board held a workshop on Evaluation of Waste Streams Associated with Light Water Reactor Fuel Cycle Options to provide a forum for developers and users of computer models and analytical tools to benchmark their results.

Board Testimony before Congress

A very important part of the Board's mandate involves advising and reporting to the U.S. Congress regarding the many technical and scientific issues associated with nuclear waste management. As discussed above, the Board sends written reports on a regular basis to Congress and the Secretary of Energy. The Board also provides information, conclusions, and recommendations in testimony presented to Congress at the request of congressional committees. During the period covered by this report, the Board provided testimony on two occasions to congressional committees, first to a Committee of the House of Representatives and then to a Senate Committee. The full text of the testimonies can be found in Appendix D.

House Committee on Energy and Commerce—On July 15, 2008, Board Chairman B. John Garrick testified before the U.S. House of Representatives Committee on Energy and Commerce, Subcommittee on Energy and Air Quality (Garrick 2008c). Dr. Garrick observed in his testimony that DOE's submittal to NRC of a Yucca Mountain license application in June 2008 was a major program milestone. He noted that because the Board performs independent peer review of DOE activities, the Board would not be a party to the Yucca Mountain licensing proceeding. The Board would contribute to the licensing process by making the results of its ongoing technical and scientific evaluation of DOE activities publicly available on the Board's website. That information could be used by anyone, including parties to the licensing proceeding. Dr. Garrick told the Committee that some technical issues that could affect calculations of repository performance had been identified by the Board before the submission of the license application. These issues included potential deliquescence-induced localized corrosion of the repository waste packages during the thermal pulse, general corrosion of waste packages, water recharge resulting from climate change, and seismicity and volcanism associated with the Yucca Mountain site.

Senate Committee on Environment and Public Works—On June 7, 2012, Daniel S. Metlay, a member of the Board's senior professional staff, was invited to testify on the history of U.S. disposal efforts and on disposal programs in other countries before the U.S. Senate Subcommittee on Clean Air and Nuclear Safety, Committee on Environment and Public Works (Metlay 2012). Among the key points in his testimony were the following:

- Site-selection strategies for deep-mined geologic repositories in the U.S. and other countries involve two "filters," one consisting of technical requirements and the other of nontechnical considerations.
- A deep-mined geologic repository is the preferred disposal option of all countries with SNF and HLW management programs.
- What characterizes national repository programs most is their variety.
- The experience of the U.S. Nuclear Waste Negotiator may be especially relevant because it is an example of a consent-based siting effort undertaken in the U.S.

- Public trust in the institutions involved in a consent-based site-selection process is an essential element for success.

Board Interactions with the BRC

Board Presentations to the BRC—On several occasions in 2010 and 2011, Board members and Board staff presented technical and scientific information on SNF and HLW management and disposal to the BRC. Board presentations to the BRC are included in Appendix E.

In July 2010, Daniel S. Metlay testified before the BRC on the experiences of programs in other countries with SNF and HLW management and disposal programs (Metlay 2010). Dr. Metlay observed that an international consensus exists that deep geologic disposal "provides a unique level and duration of protection" of public health and safety and that it is technically feasible. He pointed out that most repository siting programs rely on two "filters," a technical filter and a nontechnical filter. The filters can be employed in any order, but both must ultimately be applied. He discussed the ways in which the U.S. governmental system is different from systems in other countries where consent-based approaches have been used and noted that there are no simple solutions to complex problems.

In October 2010, Board member Mark Abkowitz appeared before the BRC (Abkowitz 2010). Dr. Abkowitz presented a description of the Board's NUWASTE systems analysis tool and some observations that had emerged as part of the NUWASTE analysis:

- Under all likely scenarios, a geologic repository will be needed for disposal of both SNF and HLW.
- Significant delays in opening a repository will substantially increase the quantity of commercial SNF in dry storage in at least 33 states.
- The NUWASTE analyses completed to date have not identified any major advantages from reprocessing in terms of either reduction in repository volume required for disposal of SNF and HLW or in uranium demand.

In November 2010, Board Chairman B. John Garrick testified before the BRC (Garrick 2010c) regarding a number of technical and scientific lessons that had been learned from the experiences of nuclear waste disposal programs in the U.S. and other countries, including the following:

- Expect surprises in the underground. At Yucca Mountain, two surprises were the discovery of "bomb pulse" chlorine-36 at the repository level and the existence of lithophysae in the waste emplacement area, which complicated geotechnical and heat-transfer modeling.
- Most disposal concepts rely on both natural and engineered barriers; an engineered system can enhance the robustness and reliability of the repository system.
- Analyzing the characteristics of the waste forms to be disposed of is important.
- A prototyping program is essential to understanding the potential performance of the components of a first-of-a kind repository system.
- Unless large dry-storage canisters can be directly disposed of, repackaging and extensive handling of the SNF they contain may be necessary.

- Disposing of SNF and HLW in many different geologic media, including tuff, granite, clay/shale, and salt, is technically feasible.

Board Comments on BRC Reports—The Board provided comments on draft reports submitted by the BRC Subcommittee on Disposal and the BRC Subcommittee on Transportation and Storage in June 2011 (Garrick 2011a and Garrick 2011b) and on the draft report of the BRC Subcommittee on Reactor and Fuel Cycle Technology in July 2011 (Garrick 2011c). The Board also commented on the draft report of the full BRC in October 2011 (Garrick 2011f) and on the final BRC report in April 2012 (Garrick 2012c). Highlights from the Board letters are provided below; the full text of the letters can be found in Appendix E.

BRC Subcommittee on Disposal

- *Need for Deep-Mined Geologic Disposal*—The Board agreed with the Subcommittee conclusion (BRC 2011b) that "one or more permanent disposal facilities for high-level nuclear waste will be needed in the United States under all reasonably foreseeable scenarios" and that "[d]eep geologic disposal has emerged as the most promising and technically acceptable option."
- *Organizational Form for the Implementer*—The Board took no position on the BRC Subcommittee recommendation that a FEDCORP-like organization be created to direct future nuclear waste management efforts. The Board said that international experience indicates that a single-purpose organization seems to work best, regardless of its other attributes (government, nongovernment, or hybrid).
- *Structure of Siting and Development Process*—The Subcommittee recommended that a "phased, adaptive approach" for siting and constructing a repository be adopted. In its letter commenting on the draft report, the Board noted that the Subcommittee's discussion does not fully reflect the strengths and the weaknesses of that approach. The Board goes on to say that, "At the theoretical level, it is hard to find fault with a decision-making strategy that seems to promise so much [in terms of potential benefits]. As a more practical matter, however, it is unclear whether it can be any more successful than earlier efforts in overcoming local and state opposition to specific siting decisions, whether it can be implemented, and whether it should be implemented."

BRC Subcommittee on Transportation and Storage

- *Subcommittee Recommendation: One or More Consolidated Interim Storage Facilities Should Be Implemented Expeditiously (BRC 2011a)*—The Board urged consideration of the system-wide implications of developing consolidated interim storage for SNF and/or HLW, as recommended by the Subcommittee.
- *Subcommittee Recommendation: Active Research Should Continue on Extended Storage Phenomena*—The Board strongly endorsed the Subcommittee's finding that an active and sustained research program is necessary to have high confidence in the safe extended storage and subsequent transportation of high-burnup fuel.
- *Subcommittee Recommendation: SNF in Storage at Decommissioned Reactor Sites Should Be First in Line for Transfer to a Consolidated Storage Facility*—The Board agreed in principle with the basis for the BRC recommendation but noted that

implementing such a preference would require either dry-transfer capability or the availability of an operational SNF pool at the interim facility.

- *Subcommittee Recommendation: Planning and Coordination for Transporting SNF and HLW Should Commence at the Start of a Consolidated Storage Program*—The Board concurred with the Subcommittee recommendation and noted that there are inconsistencies in NRC's regulations for transportation and storage that need to be addressed. Also, the Board noted that while the safety record for transporting SNF is excellent, the scale of the transportation campaign needed to transfer SNF and HLW to one or more consolidated storage facilities would dwarf previous efforts.

BRC Subcommittee on Reactor and Fuel-Cycle Technology

- *Subcommittee: There is a need to provide "near-term improvements in the safety and performance of existing light-water reactor technology as currently deployed in the United States" and the need for "longer-term efforts to advance potential 'game-changing' nuclear technologies and systems that could achieve very large benefits across multiple evaluation criteria compared to current technologies and systems"* (BRC 2011c). The Board commented in its letter to the Subcommittee that it believed that consideration of improvements in existing technologies and development of new nuclear technologies should include the waste-stream consequences of the adoption of the changes as part of the decision-making process, and that "any evaluation of the benefits of such changes should take into account the impact on the waste management requirements that will result from the adoption of the changes."

- *Subcommittee: "No currently available or reasonably foreseeable reactor and fuel cycle technologies—including current or potential reprocess and recycle technologies—have the potential to fundamentally alter the waste management challenge this nation confronts over at least the next several decades, if not longer."* The Board essentially concurred with this BRC finding and reiterated the importance of moving on to a disposal solution, which ultimately will be required regardless of waste form(s). The Board went on to say that, in its view, a disposal facility should not be delayed by research and development (R&D) on fuel-cycle alternatives.

BRC Draft Report to the Secretary of Energy

On October 31, 2011, the Board sent a letter to BRC Co-Chairs Lee Hamilton and Brent Scowcroft commenting on the BRC's Draft Report to the Secretary of Energy, dated July 29, 2011 (BRC 2011d). Following are some observations from the Board's letter:

- *Deep Geologic Disposal:* "The Board strongly concurs with the Commission's findings that deep geologic disposal is the most promising and accepted method currently available for safely isolating spent nuclear fuel (SNF) and high-level radioactive waste (HLW) for very long periods and that a permanent repository will be needed for any fuel cycle option that might be implemented in the reasonably foreseeable future."

- *Developing Generic Siting Criteria:* "The Board concurs with the Commission that development of generic repository siting criteria should

proceed without delay. The Board notes that from a technical perspective, generic studies do not replace the need to focus on specific geologies and potentially available sites in the United States that may meet the criteria."

- *Deep Borehole Disposal:* "While deep boreholes are suggested in the Commission's Draft Report as a substitute for mined geologic disposal, the Board recommends additional RD&D on deep borehole disposal to help resolve uncertainties about this approach and to allow for a more conclusive evaluation of its feasibility."
- *Radiation Source Term:* "The Board believes that determining the radiation source term realistically, particularly with respect to the processes involved in mobilizing the waste, is critical to obtaining a fundamental understanding of the disposition of dose-contributing radionuclides. Such analyses can potentially help support a repository compliance case and can provide a much more credible understanding of how natural and engineered barriers would work together in a repository to contain and delay the release of radionuclides from the waste into the accessible environment."
- *Extended Storage of SNF:* "The Board concurs strongly with the Commission that research is needed on fuel degradation mechanisms and other factors that may affect the ability to store SNF for long periods. As discussed in the Board's report on Extended Dry Storage and Transportation of Used Fuel, issued in late 2010 [NWTRB 2010a], the Board recommends that the ability to handle and transport such waste after extended storage also should be studied."
- *Management of DOE SNF and HLW:* "The discussion of the wastes stored at these facilities in the Commission's Draft Report correctly reflects the importance of considering how defense wastes should be managed and disposed of when evaluating options for permanent disposal of high-activity waste. The Board believes that a full discussion of the issues related to the need to permanently dispose of these wastes should be included in the Commission's final report."
- *Systems Approach to Study of Alternative Fuel-Cycle Technologies:* "The Board has consistently urged DOE to adopt a 'systems' approach to radioactive waste management and strongly supports the Commission's finding that studies of alternative fuel-cycle technologies should account for linkages among all elements of the fuel cycle, including reactor technologies, fuel processing, transportation, storage, and disposal of SNF and HLW."
- *Technical Basis for Taking Burnup Credit:* "The Board advocates developing a technical basis for taking full credit for the loss of fuel reactivity as a result of burnup. The Board believes such work should have high priority because taking burnup credit potentially offers significant economies in developing a transportation system and cost savings at other stages of a spent fuel management program."
- *International Experience:* "The Board has found its interactions with programs in other countries to be extremely valuable and joins the Commission

in urging that U.S. program managers take full advantage of the experiences gained."

- *Preservation of Yucca Mountain Data and Documents:* "The Board believes that it is imperative that information and data generated previously by the Office of Civilian Radioactive Waste Management be preserved in a reasonably accessible (electronic) form and recommends that the final Commission report address this important issue."

BRC Final Report to the Secretary of Energy

Following are comments from the Board's April 18, 2012, letter to Secretary Chu (Garrick 2012c) on the final BRC Report (BRC 2012).

- "Lessons learned from U.S. and international experience should be taken into account in developing guidelines, for siting, for the solicitation of volunteer sites, and for integrating the overall process. In particular, lessons learned from the failure of the Nuclear Waste Negotiator approach should inform any consent-based volunteer-siting process."
- "Because spent fuel and high-level wastes are quite different in volume and activity, we think that a technical study to determine whether to separate commercial spent fuel from defense and DOE waste should be expeditiously completed in order to help establish a clear vision and mission for the organization charged with implementing the waste storage and disposal program."
- "The bore-hole concept has simply not yet been vetted technically to the extent that deep-mined geological disposal has. Furthermore, the need to disassemble fuel assemblies to implement bore-hole disposal would result in unnecessary worker exposure, and a decision to use bore holes might preempt retrievability options at a later time."
- "From a technical point of view, the Board generally supports the development of underground research laboratories as a preliminary step in designing and constructing a full-scale geologic repository."
- "With the curtailment of the Yucca Mountain Project, the appeal for this interim step [consolidated storage] increases since it is not clear when a disposal site might be available."
- "In order to handle the massive shipments of spent fuel that will be involved and to implement the needed infrastructure in terms of rail cars and handling systems, work [on transportation] needs to be started now."
- "…we support the need to review the outdated waste classification system and make it based on the form and activity of the waste rather than its source."

Board Interactions with the Interested Public and with Radioactive Waste Management Programs in Other Countries

Interacting with the Public—An important fixture of each Board public meeting is the public comment session, where members of the interested public are invited by the Board to

comment and ask questions regarding the information presented at the meetings. Over the past 25 years, Board meetings have provided a unique forum for the public to interact directly with the Board and its staff; DOE program managers, scientists, engineers, and consultants; and other program participants. The public comments offered at the meetings are included in meeting transcripts, and written materials submitted by public commenters at Board meetings are included in the meeting records on the Board's website.

Interacting with SNF and HLW Programs in Other Countries—Since its inception, the Board has interacted in various ways with SNF and HLW management and disposal programs in other countries. The objective of these interactions has been to gain knowledge, perspective, and insights from the experiences of these programs that can enhance the Board's review of DOE activities. During the five years covered by this report, small delegations of Board members and staff visited SNF management programs in several countries, including Finland, France, Sweden, and the United Kingdom. The Board also hosted representatives of some programs when they visited the U.S. and included them in Board meetings, when appropriate.

During the five years covered by the report, Board Chairman B. John Garrick participated in several meetings of the Advisory Bodies to Government (ABG), which was established by the Organization for Economic Cooperation and Development's Nuclear Energy Agency. The ABG provides a forum that allows the chairs and assigned staff of organizations similar to the Board to exchange views informally. Currently, Chairs from the organizations in six countries (France, Germany, Sweden, Switzerland, the United Kingdom, and the United States) participate in the meetings, which are held approximately every 18 months.

Lessons Learned—Partly at the suggestion of a representative of an affected unit of local government during a public comment session at one of the Board's meetings, the Board held meetings in October 2010 and in February 2011, at which panels discussed potential "lessons learned" from the Yucca Mountain project and from the experiences of nuclear waste disposal programs in other countries (NWTRB 2010b and NWTRB 2011). The panels included former Yucca Mountain program managers, representatives of local governments and stakeholder groups, and representatives of international waste management and disposal programs. All materials and records related to these meetings are available on the Board's website.

Board Review of DOE Activities Related to Implementing the NWPA - Significant Issues

During the period covered by this report, the Board held 15 public meetings, at which DOE and its contractors presented their technical and scientific work related to implementing the NWPA. A chronological listing of the meetings can be found in Appendix F.

As discussed earlier, until 2010, DOE's SNF and HLW R&D focused primarily on activities and investigations related to supporting a Yucca Mountain license application. After 2010, much of the R&D undertaken by DOE transitioned to generic studies, including investigations of different geologic media. The Board's technical and scientific review of DOE's work continued through this transition.

In accordance with established practice and to ensure the timeliness of Board comments, after every public meeting the Board sends follow-up correspondence to DOE, which

includes comments and recommendations on DOE activities discussed at the meetings. Board correspondence with DOE from January 1, 2008, through December 31, 2012, is included in Appendix G. Significant Board comments from some of these follow-up letters have been organized according to technical and scientific topic and are summarized in the following sections.

Yucca Mountain

Total System Performance Assessment (TSPA)—The Board made the following comments on TSPA assumptions, methods, and results in a letter to DOE in September 2008 (Garrick 2008d):

- DOE analyses show that the engineered barrier system contributes very significantly to overall repository performance.
- DOE sometimes uses what it considers conservative assumptions about the features or processes being modeled while taking an opposite approach in other instances.
- Assumptions and methods in TSPA-LA are not consistently well supported.

In the same letter, the Board made the following recommendations for enhancing confidence in the assumptions, methods, and results supporting TSPA-LA:

1. The technical basis for screening out deliquescence-induced localized corrosion should be improved.
2. Prototypes of novel engineered systems should be developed.
3. Fundamental understanding of the geologic environment should be enhanced.

DOE responded to the Board's recommendations in a letter to the Board in September 2008 (Sproat 2008b), stating that the Yucca Mountain license application had been docketed with NRC, and from that point, DOE "does not intend to formally respond to issues regarding the [license application] raised by the NWTRB or others outside the context of the licensing proceeding." Chairman Garrick responded to DOE (Garrick 2008e) by clarifying the Board's statutory mandate, which requires the Board to continue its technical and scientific evaluation of DOE activities until no later than one year after the date on which DOE begins disposing of SNF and HLW in a repository. Dr. Garrick went on to state that "the Board's responsibilities under the law require it to continue its evaluation of the technical and scientific validity of the full range of activities undertaken by the Secretary of Energy to implement the Nuclear Waste Policy Act and its amendments."

Drip Shield Performance—The drip shields, which would be placed over and around waste packages to divert water and deflect rock fall, are an important part of the engineered barrier system for a Yucca Mountain repository. In an August 2009 letter to Secretary Chu (Garrick 2009c), the Board noted that DOE had not developed prototypes for equipment that would emplace, monitor, inspect, adjust, or, if necessary, retrieve the drip shields. The Board recommended developing prototypes for the drip shields and for the equipment that would be used to install and maintain them. The Board also told DOE that the cumulative effects of modeling assumptions in the license application "may result in a lack of realism about how barriers and waste would behave in a repository." The Board urged DOE to develop more realistic models.

Thermal-Loading Strategy—The thermal-loading strategy for the Yucca Mountain repository also has important implications for repository capacity and performance. In reviewing DOE's repository design, the Board observed in a letter to DOE in April 2008 (Garrick 2008b) that a better justification was needed for the thermal limits established by the program. The Board recommended that DOE investigate the feasibility and technical advantages of determining thermal limits at repository closure and varying the duration of ventilation accordingly.

Emplacement Drift Stability—The Board pointed out in its April 2009 letter to DOE (Garrick 2009a) that the lithophysal tuff, in which 85 percent of the repository emplacement drifts would be located, contains cavities that are highly heterogeneous in size and spatial distribution. The other 15 percent of the repository rock appeared to be stronger, more uniform, and better characterized. Testing being done by DOE at the time was in non-representative intact lithophysal rock, not in rock with abundant fracturing, typical of the rock in the emplacement zone. The Board recommended conducting full-scale or near-full-scale thermomechanical testing of fractured lithophysal tuff to help validate models and estimates. In a June 2009 response to the Board, DOE disagreed with the value of full-scale testing, stating that "existing data and models provide conservative estimates of the drift response."

Deliquescence-Induced Localized Corrosion of Repository Waste Packages—In a letter to DOE sent in 2007 (Garrick 2007), the Board had raised concerns about the potential for deliquescence-induced localized corrosion of the repository waste packages after they were emplaced in the repository. DOE presented its latest work on this issue at a Board meeting held January 16, 2008 (Russell 2008). In a follow-up letter to DOE (Garrick 2008b), the Board said that it continued to have questions about the technical basis for DOE's decision to exclude deliquescence-induced localized corrosion from the TSPA and recommended, among other things, that DOE improve its understanding of the evolution of the waste package environment.

Waste Package Closure—In an April 2009 letter to DOE (Garrick 2009a), the Board noted that development of a complex prototype system for closure of a loaded waste package was being studied at the Idaho National Laboratory. The Board asked for more information on the potential advantages of evacuating and filling the inner waste packages with an inert gas and pointed out that tolerances between the lid and the waste package seemed very tight. DOE acknowledged in a June 2009 response to the Board (Kouts 2009b) that this was an important technical issue.

Dual-Purpose Canisters (DPCs) —The Board commented in a letter to DOE (Garrick 2009a) that, based on information provided by the Electric Power Research Institute in a presentation at the Board's January 2009 meeting (Machiels 2009), it appeared that the potential for criticality of some or many of the already loaded dual-purpose canisters (DPCs) may be low enough to permit direct disposal in a repository. The presentation also indicated that criticality potential could be reduced and shielding could be improved by placing more reactive fuel assemblies in the periphery of the DPC. However, such loading could increase temperatures at the DPC centerline. The Board recommended that, when funding would permit, DOE should investigate direct disposal of DPCs because transferring SNF into transportation, aging, and disposal (TAD) canisters would require cutting open the DPCs and repackaging the waste.

In an August 2009 letter to Secretary Chu (Garrick 2009c), the Board called attention to the fact that while DOE had contracted with cask manufactures to develop designs for TAD canisters, nuclear utilities were using dry-storage canisters that held significantly more SNF and produced a higher heat load than intended for TAD canisters, and the trend was for the capacity of the dry-storage canisters to increase in the future. The Board recommended consideration of direct disposal of loaded dry-storage dual-purpose canisters, noting that direct disposal would require full burnup credit and an increase in the diameter of TAD canisters.

Surface-Facility Design—In commenting on DOE's work related to Yucca Mountain surface-facility designs (Garrick 2008f), the Board observed that DOE had not provided clear explanations of the following:

- Why surface facilities were designed with four-foot-thick walls
- The percentage of completeness, at the time, of the facility designs
- How the SNF-pool cooling and cleanup systems would operate

Moreover, many of the design elements appeared to be non-standard, suggesting that in designing the system, DOE had not benefited from the experience of the nuclear industry. The Board recommended reevaluating the seismic aspects of the design basis for consistency with commercial nuclear facilities and addressing what appeared to be excessively robust design of facilities that would not need to be operational over periods of hundreds of thousands of years.

In a February 2009 response to the Board (Kouts 2009a), DOE pointed out that nuclear facility structures must meet two requirements: (1) code requirements for seismic forces resulting from design-basis ground motion, and (2) design margins adequate to meet performance requirements of 10 CFR Part 63, *Disposal of High-level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*, for ground motions beyond design basis.

Surface Facility Throughput—In a letter to DOE (Garrick 2008b), the Board noted that in analyzing the throughput of repository surface facilities, DOE assumed that loaded transportation casks and empty waste packages would be available on-demand and that empty transportation casks and loaded waste packages could be moved efficiently through the system. However, the Board said that the availability of these containers likely will fluctuate for various reasons. The Board suggested that more realistic modeling assumptions and a more integrated analysis might show that additional transportation equipment and surface facilities, including aging pads, would be required to achieve the desired throughput. The Board added that confidence in the performance of surface facilities could be enhanced by analyzing the performance of surface facilities under conditions of minimum capacity and maximum rate of receipt to test operations under stress. DOE responded in a letter to the Board (Sproat 2008a) that DOE had included operational and design contingencies to account for uncertainties in the mix of TAD-canistered to non-TAD canistered SNF. DOE went on to say that options similar to those raised by the Board had been assessed, and the conclusion was that the proposed facilities are expected to meet DOE's operational requirements.

The Board's views were reiterated in a November 2008 letter to DOE (Garrick 2008f), in which the Board suggested that additional conditions should be evaluated, such as

- Delays in the construction of the rail line from Caliente to Yucca Mountain
- Delays in the deployment of TAD canisters beyond 2013
- The possibility that less than 90 percent of SNF would arrive in TAD canisters
- Seasonal variations in the receipt rate of SNF
- Delays in the receipt of DOE waste, or not receiving DOE waste in the order needed
- Less than 75 percent of the surface facilities being available
- Occurrence of upset conditions in any part of the system
- Utility sites lacking usable rail access
- Need to accommodate SNF in storage
- Potential disposal of SNF in dual-purpose casks

DOE responded in a February 2009 letter (Kouts 2009a) that prototyping had or would be done on waste packages and associated equipment, the waste package closure system, and the dual-purpose cask-cutting machine.

Construction of a Rail Spur to Yucca Mountain—In an April 2008 letter to the Board (Sproat 2008a), DOE said that the most practicable solution for SNF transportation in Nevada was expeditious development of a new rail line. In an April 2008 letter to DOE (Garrick 2008b), the Board reiterated a previous recommendation that DOE should initiate contingency planning to identify alternatives to rail transport that could be implemented if significant delays were encountered during construction of the rail spur.

DOE Preservation of Yucca Mountain Data and Documents—After funding for Yucca Mountain was eliminated and DOE notified NRC of its intention to withdraw the Yucca Mountain license application, responsibility for archiving and preserving Yucca Mountain scientific and engineering information passed to DOE's Office of Legacy Management. The Board's review of the resulting DOE activities started in 2010 as part of the Board's ongoing evaluation of DOE activities and continued at the direction of the House Appropriations Committee (U.S. House 2011). DOE updated the Board on its legacy management activities at a Board meeting held in September 2011 (Parks 2011). The Board's review of these DOE activities included visits to DOE facilities in Las Vegas, Nevada, and a "spot check" retrieval exercise at the DOE Legacy Management facility in Morgantown, West Virginia, in August 2012.[3]

Generic Investigations and Analyses

Deep Geologic Disposal—In a March 2012 letter to DOE following its January 9, 2012, public meeting (Garrick 2012b), the Board reiterated its concurrence with the finding that deep geologic disposal continues to be the most promising and accepted method currently available for safely isolating SNF and HLW. Given this, the Board recommended that DOE initiate the following actions without delay:

- Development of generic site-selection criteria

[3] The Board's report on DOE's work in this area was released in August 2013. The report will be discussed in a subsequent summary report of Board activities.

- Development of a realistic understanding of the source term
- Because of the prospect of extended storage of SNF, development of a better understanding of fuel-degradation mechanisms, especially for high-burnup fuel

Generic Research on Disposal Options—At a Board meeting held in September 2011, DOE presented its plans, based on systems engineering techniques, for studying disposition options, including deep-mined geologic repositories in salt, granite, and clay/shale formations and deep borehole disposal (Swift 2011). In a follow-up letter sent in December 2011 (Garrick 2011h), the Board acknowledged DOE's efforts and urged DOE to strengthen its interactions with SNF and HLW management programs in other countries to take advantage of the wealth of relevant information that had been amassed and to avoid duplicating the research of other programs.

Salt Disposal Investigations with a Field-Scale Heater Test at the Waste Isolation Pilot Plant—In a January 2012 letter (Garrick 2012a), the Board told DOE that it supported generic R&D tasks in the context of geologic repository program development, as long as they are (1) based on realistic concepts of host rock geology; (2) focused on identifying and evaluating significant features, events, and processes and their constitutive relationships; and (3) shown to reduce uncertainties and adverse risk related to generic technical and scientific objectives. In terms of the Salt Disposal Investigations proposal that had been prepared by DOE and issued in June 2011, the Board noted that the proposal did not specify the basis for the proposed work. Instead, the proposal identified gaps in experimental work and modeling and proposed R&D activities that did not appear to be ranked by their importance in meeting generic repository objectives. The Board said that not presenting an explicit evaluation of generic salt information needs in the context of a relevant uncertainty and risk assessment was a significant shortcoming of the proposal. Following are some additional points from the letter:

- It was difficult to assess the importance of work in salt compared with work in other geologic media without knowing the basis for the selection of salt. The Board could not make a proper evaluation of the salt proposal without knowing what alternatives were under consideration.
- It was unclear whether the proposed tests at the Waste Isolation Pilot Plant (WIPP) were intended to investigate the suitability of generic salt as a repository medium or the potential of bedded salt for such a purpose. In either case, the proposal should also provide the technical basis for performing the proposed testing at WIPP.

Fuel Disposition Program—The Board wrote to DOE in October 2010, following up on the Board's June 2010 meeting (Garrick 2010a). The Board said in the letter that as DOE developed its Used Fuel Disposition Program, it should consider an approach similar to one established in 2003 by DOE to develop scientific and technical information. The Science and Technology program assembled several teams of highly qualified engineers and scientists who, until the program was terminated, produced significant results. The Board said that a similar effort was needed for the Fuel Disposition Program because the scope of scientific and technical options had grown. The Board noted that the success of such an effort depended on continuity in leadership and funding.

Canister and Waste Package Temperatures—Waste package temperatures were discussed at a meeting of the Board held in October 2012, in Idaho Falls, Idaho. At that meeting, there was discussion of an "open" repository design that would allow for ventilation of the repository drifts containing the waste packages in order to remove some heat before repository closure. The presentations at the meeting indicated that there might be more flexibility than previously assumed in waste-package sizes (Adkins 2012 and Hardin 2012b). The Board recommended in a December 2012 letter to DOE (Ewing 2012b) that this work should continue.

Deep Borehole Disposal—At the Board's February 2011 meeting, DOE provided information supporting the case that many geologic media in the United States would be suitable for geologic disposal (Hardin 2011). Also discussed was potential testing of deep borehole disposal as an option for some waste, including field investigations, a test drilling program, and emplacing surrogate SNF and HLW in a borehole (Brady 2011, Hardin 2011, and Orrell 2011). In a letter to DOE following the meeting (Garrick 2011e), the Board said that if such a testing program were to go forward, it should be coupled with a program for developing the appropriate facility designs and evaluating the necessary operational requirements for a deep borehole disposal program. The Board asked for more information on DOE's deep borehole disposal activities and other geology-specific disposal programs that were under consideration. The Board was particularly interested in work directed at optimizing the characteristics of the waste forms intended for disposal in specific geologic media. In a December 2011 follow-up letter to DOE on information presented at a September 2011 Board meeting (Garrick 2011h), the Board said that in establishing research priorities, "when compared with mined deep geologic disposal, the development of deep borehole disposition as a potential waste management option should be given a lower priority."

In a March 2012 letter to DOE (Garrick 2012b), the Board noted that it had on several occasions recommended that consideration be given to different methods of geologic disposal for different high-activity waste, such as minor actinides or vitrified fission products, which have no apparent value for reuse. However, the Board acknowledged that there might be significant complications associated with using deep borehole disposal for other wastes. For example, current technology would require SNF to be repackaged into small-diameter containers that would fit the borehole. The Board said that the increased handling of SNF would be, at best, "highly undesirable." The Board made the following comment: "In the Board's view, research related to deep borehole disposal should not delay higher priority research on a mined geologic repository. However, if that condition can be met, the Board believes that DOE should continue its research on deep borehole disposal. This information would provide a realistic basis for comparison with other geologic disposal options."

Suitability of Yucca Mountain Canisters for Other Geologies—In a letter to DOE in October 2010 (Garrick 2010b), the Board recommended that studies be undertaken to determine whether the packaging developed for a Yucca Mountain repository would be suitable for other geologies. The Board suggested that DOE look at work already underway or completed in the U.S. and in other countries.

Repackaging of SNF—This subject was discussed in a presentation at a meeting of the Board on January 9, 2012 (Hardin 2012a and Williams 2012). In its March 2012 letter to DOE following the meeting (Garrick 2012b), the Board noted that the presentations con-

veyed an essential message: "Decisions about waste packaging and storage that have been or are being taken may have a profound effect on repository design." The Board recommended that DOE consider the existing and expected inventory of SNF in storage as a waste form that needs to be disposed of in a geologic repository.

SNF and HLW Storage and Transportation

Modeling the Transportation System—Questions raised by stakeholders and the interested public at the Board's October 2012 meeting in Idaho Falls, Idaho, made clear that transportation of SNF and HLW remained a major concern. In the Board's December 2012 letter to DOE following the meeting (Ewing 2012b), the Board said that the transportation modeling results presented by DOE at the meeting did not reflect possible upset conditions or the possibility of transportation to multiple sites. The Board urged DOE to attach a high priority to ensuring that cask licenses and yet-to-be-fabricated casks would be available to support DOE's transportation requirements and schedule.

Very Long-Term Dry Storage of SNF—The Board held a meeting in June 2009, at which it invited a panel of experts to discuss research and data needs for extended (120 years or more) dry storage of SNF (NWTRB 2009a). In a letter to DOE Secretary Steven Chu following the meeting (Garrick 2009c), the Board noted that extended dry storage of SNF and HLW was likely, and there appeared to be no technical factors that would prevent designing and safely operating dry-storage systems for decades, providing that there is regular monitoring. However, it was not clear at that time whether a technical basis existed for operating dry-storage systems for very long periods. On the basis of discussions among panelists at the meeting, the condition of the SNF in dry-storage canisters appeared to be the most important factor to be considered in analyzing the effects of extended storage because the SNF must be shipped, possibly repackaged, and eventually disposed of (or reprocessed) after a long period in dry storage. Addressing this issue is complicated by the situation in the U.S. where experience is limited to the examination of a few fuel assemblies with burnups that are significantly lower than current practice.

In an October 2010 letter to DOE (Garrick 2010a), the Board recommended studies to identify necessary actions for preventing problems during transportation, repackaging, or disposal of DOE SNF following extended storage.

In December 2011, the Board commented in a letter to DOE (Garrick 2011g) on DOE's draft *Gap Analysis to Support Extended Storage of Used Nuclear Fuel* issued June 30, 2011. In particular, the Board was interested in learning more about why the delayed hydride cracking degradation mechanism was designated in the Gap Analysis as a medium and not a high research priority. Among other things, the Board underscored the need to carry out additional cask-demonstration and fuel-inspection projects and recommended characterizing SNF before dry storage to establish a baseline, against which to monitor changes in fuel condition during storage. The Board recommended opening representative casks periodically to identify changes from the baseline conditions and encouraged DOE to take advantage of similar work being done in other countries. The Board also supported research by DOE to quantify the amount of residual water that remains in casks after drying and to develop new monitoring instrumentation.

In a letter following its September 2011 meeting (Garrick 2011h), the Board raised additional issues that it believed needed to be addressed related to DOE's studies on extended storage and subsequent transportation of SNF and HLW, including:

- The potential that operations might be undertaken today that would limit future options in managing SNF and HLW.
- The dose and cost implications of needing to repackage SNF.
- The implications of requiring early removal of SNF from reactor storage pools in response to concerns caused by the events at Fukushima Daiichi in March 2011.

Nuclear Fuel Cycle

Implications of Fuel-Cycle Technology for Waste Management—At a Board meeting held in February 2011, DOE presented its plans for R&D on fuel-cycle technology that would be undertaken by DOE's Office of Nuclear Energy (Boyle 2011 and Regalbuto 2011). In a follow-up letter (Garrick 2011e), the Board noted its particular interest in the implications of these studies for SNF management and disposal, including the effects on the quantities and volumes of waste that would be generated. The Board was especially interested in DOE's work on the "once-through" fuel cycle and limited recycling because other options "do not appear to have the potential to be deployed in the next few decades."

At a meeting held in Arlington, Virginia, in January 2012, the technical and institutional complexities of integrating activities throughout the nuclear fuel cycle were presented by DOE (Regalbuto 2012 and Wigeland 2012). In a March 2012 letter to DOE following up on that meeting (Garrick 2012b), the Board strongly encouraged DOE to work with nuclear utilities in developing approaches for managing the storage and disposal of SNF and HLW to ensure that "pieces" of the strategy work together. The Board noted concerns with a comprehensive fuel-cycle evaluation project that was in the early stages:

- There seems to be a risk that comprehensiveness will be purchased at the price of relevance.
- Simplifying the analysis would have the added benefit of increasing the timeliness of the results of the analysis.
- Methodological challenges to carrying out this type of evaluation are significant.
- Only a very abbreviated description of the study was available publicly.
- The conclusions of the study should not go beyond what can be reasonably and conservatively inferred.

Disposal and Management of DOE SNF and HLW

Implications of Delay in Repository Development—Following its June 2010 meeting, the Board wrote to DOE (Garrick 2010b) recommending that as-built lifetimes (as opposed to design lifetimes) of SNF dry-storage systems at the Idaho National Laboratory should be assessed with the understanding that a date for constructing a repository or storage facility had not been established and that that uncertainty could continue well into the future.

The Board noted in a July 2011 letter following an April 2011 meeting at the West Valley Demonstration Project (WVDP) (Garrick 2011d) that a key assumption in disposing of the vitrified waste at WVDP was that a Yucca Mountain repository would be available to take the waste at a time within the facility planning horizon. A repository other than Yucca Mountain might have trouble accepting the five- and seven-canister multiple purpose casks, which were planned for use at West Valley. The Board recommended that the

WVDP maintain flexibility in its relocation project to adapt to future changes in repository design and schedule.

Integration and Sharing of Program Data—The Board has always placed a high priority on integration of information among entities that are part of the waste management system. After the Board's visit to WVDP in April 2011, in a letter to DOE (Garrick 2011d) the Board invited a representative from the WDVP to participate in a later Board meeting, at which procedures in place at DOE's Office of Environmental Management for preserving and sharing information would be discussed. The Board emphasized the importance of sharing decommissioning information among facilities across the DOE complex. The Board recommended that the DOE Office of Nuclear Energy and the DOE Office of Environmental Management share such information.

Calcined Wastes—The Board noted in a letter following up on its June 2010 meeting in Idaho (Garrick 2010b) that the design lifetime of 500 years for storing solid granular calcined waste in shielded bins made of ferrous alloys and concrete was unprecedented. The Board recommended examining in detail the technical basis for the lifetime estimate associated with the design. DOE chose hot isostatic pressing as a treatment method for the calcine before it was transported off site. A key technical assumption affecting this decision was that treated calcine would be loaded into canisters that were 2 feet in diameter by 10 or 15 feet long. These canisters would be loaded into TAD canisters. This assumption could increase the number of containers requiring storage, transportation, and disposal. It was not clear from DOE presentations whether the operational risks of alternative treatment options were compared or if probabilistic risk assessments were performed on the safety of alternatives after disposal in a repository. The Board recommended another cost comparison to take into account technical assumptions and operational risks of various treatment options.

Sodium-Bearing Waste—The Board suggested in its October 2010 letter to DOE (Garrick 2010b) that a risk assessment could help determine whether sodium-bearing waste (SBW) is a high-level radioactive waste. In the same letter, the Board concurred with DOE that changing SBW from a liquid to a solid waste was necessary. In another letter on this subject sent to DOE in December 2012 (Ewing 2012a), the Board stated that, at that time, it had no technical reason to question DOE's decision to manage SBW as transuranic-contaminated (TRU) waste. Because TRU waste falls outside the Board's statutory purview, the Board indicated it would not comment on the execution of DOE's plan to process SBW. The Board recommended that DOE formalize the classification of the material before processing it and noted that if the designation should change in the future, it might be necessary to dispose of SBW as HLW. The Board asked to be kept informed of that eventuality.

Management and Disposal of Melter from WVDP—In a July 2011 letter to DOE following its April 2011 meeting (Garrick 2011d), the Board noted that DOE had issued a draft determination in March 2011 that the melter from the vitrification plant at WVDP could be managed and disposed of as low-level waste. The Board observed that this determination could set a precedent for the disposal of melters at Hanford and the Savannah River Site and recommended that DOE take this into account in finalizing the determination.

Future Plans

Since the end date of this report, the Board has actively continued its evaluation of DOE activities and of issues related to SNF and HLW management and disposal, including the preservation of Yucca Mountain data and documents, factors affecting deep borehole disposal, the implications of the continued dry storage of commercial SNF in large canisters at U.S. nuclear utility sites, and the management of DOE SNF that will require disposal. The Board will provide its findings, conclusions, and recommendations on these and other issues in upcoming reports to the U.S. Congress and the Secretary of Energy.

Abbreviations and Acronyms

ABG	Advisory Bodies to Government
Board	U.S. Nuclear Waste Technical Review Board
DOE	U.S. Department of Energy
DPC	dual-purpose canister
FEDCORP	Federal Corporation
HLW	high-level radioactive waste
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
NWTRB	U.S. Nuclear Waste Technical Review Board
OCRWM	DOE Office of Civilian Radioactive Waste Management
SBW	sodium-bearing waste
SDI	Salt Disposal Investigations
SNF	spent nuclear fuel
TAD	transportation, aging, and disposal canister
TSPA	Total System Performance Assessment
TSPA-LA	Total System Performance Assessment – License Application
TRU	transuranic waste
WIPP	Waste Isolation Pilot Plant
WVDP	West Valley Demonstration Project

Glossary of Terms

back end of the nuclear fuel cycle All activities related to processing, storage, and/or final disposal of spent nuclear fuel and high-level radioactive wastes.

bomb-pulse chlorine-36 See **chlorine-36**.

Blue Ribbon Commission on America's Nuclear Future (BRC) A temporary commission formed by former Secretary of Energy Steven Chu to (1) review policies for managing the back end of the nuclear fuel cycle and (2) recommend a new strategy.

branch line A secondary railway line, which branches off a more important through route, usually a main line. A very short branch line may be called a spur line.

burnup A measure of reactor fuel consumption expressed as the percentage of fuel atoms that have undergone fission, or the amount of energy produced per unit weight of fuel.

calcination A process of drying and heating substances in air to sufficiently high temperatures so that oxides of the constituents are produced. A technique usually employed for processing of residues from evaporation of liquid wastes.

calcine A general term for the granular, dehydrated ceramic powder created when high-level radioactive waste and certain chemical additives are heated to a high temperature in air.

chlorine-36 (36Cl) A long-lived radioactive isotope of chlorine produced by irradiation of natural chlorine, argon, or other materials by cosmic rays or neutrons. Atmospheric testing of nuclear weapons in the 1950s temporarily increased concentrations of chlorine-36 in the area of the tests. The resulting "bomb-pulse" levels of chlorine-36 can sometimes serve as a tracer to determine how rapidly precipitation from the 1950s has moved through soil and rocks, such as those present at Yucca Mountain.

clay Sediment composed of rock or mineral fragments smaller than 4 microns. Also, the geological strata formed from such sediments. Clays typically have relatively low permeability and relatively high capacity for sorption of positively charged chemical species.

conservative estimates Projections of repository performance using parameters and models that systematically underestimate the system's ability to isolate and contain waste.

Construction Authorization Board (CAB) A Board established by the Nuclear Regulatory Commission to preside over petitions to intervene and requests to participate in the Yucca Mountain licensing proceeding.

corrosion Progressive surface dissolution of a material, generally metal. In radioactive waste management, it is also used for glasses and ceramic waste forms. Corrosion can be uniform over the surface of the material or non-uniform through enhanced corrosion in stressed areas at physical discontinuities. Selective localized formation of rounded cavities on the surface is called pitting corrosion.

criticality A reactor achieves criticality (and is said to be critical) when each fission event releases a sufficient number of neutrons to sustain an ongoing series of reactions. In nuclear waste management, criticality refers to the probability and circumstances under which a quantity of waste could achieve criticality.

decommissioning Administrative and technical actions taken to remove nuclear fuel and radioactive material from a facility and to allow the removal of some or all of the regulatory controls. This does not apply to a repository or to certain nuclear facilities used for mining and milling of radioactive materials, for which the term "closure" is used.

deliquescence The absorption of atmospheric water vapor by a solid salt to the point where the salt dissolves into a saturated solution.

drift An underground opening or tunnel that is used for access/egress, to facilitate repository construction, ventilation, and transportation and emplacement of nuclear waste.

drip shield Barriers placed over and around waste packages to divert water from the packages and deflect falling rocks from impacting the waste package.

dry-cask storage system Any system that uses a cask or canister as a component in which to store spent nuclear fuel without using water to remove decay heat. A dry-cask storage system provides confinement, radiological shielding, physical protection, and inherently passive cooling of the spent nuclear fuel.

dual-purpose canister (DPC) A transportable storage cask, which has been licensed for the storage and transportation of spent nuclear fuel by the Nuclear Regulatory Commission.

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

features, events, and processes (FEPs) Used in the field of radioactive waste management to define relevant scenarios for safety assessment studies.

FEDCORP A self-sustaining, quasi government entity that would manage the federal government's responsibilities for managing and disposing of spent nuclear fuel and high-level radioactive waste.

field-scale heater test Large-scale tests that use electric heaters to simulate nuclear waste canisters.

fuel cycle All operations associated with the production and use of nuclear fuel, including mining and milling, processing and enrichment of uranium or thorium, manufacture of nuclear fuel, operation of fuel in nuclear reactors, reprocessing of nuclear fuel, related research and development activities, and all activities related to radioactive waste management, including disposal.

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

geotechnical engineering The branch of civil engineering concerned with the engineering behavior of earth materials.

granite Broadly applied, any holocrystalline quartz-bearing plutonic rock. The main components of granite are feldspar, quartz, and as a minor essential mineral, mica.

Hanford A 586-square-mile site located in southeastern Washington state. Beginning in 1943, the site was used to produce plutonium for the Manhattan Project and later for other weapons. The last reactor at the site ceased production in 1987, but solid and liquid wastes from weapons-production processes remain at the site. In 1989, the U. S. Department of Energy, the U.S. Environmental Protection Agency, and Washington State Department of Ecology entered into a legally binding accord, the Tri-Party Agreement (TPA), with the objective of cleaning up the Hanford site.

heterogeneous A quantity of material that is non-uniform and may consist of dissimilar or diverse ingredients or constituents.

high-burnup fuel Reactor fuel with burnups exceeding 45 GWd/MT.

high-level radioactive waste (HLW) Highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly from reprocessing and any solid material derived from such liquid waste that contains fission products in concentrations above levels specified in regulations. Any other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines requires permanent isolation by disposal in a geologic repository.

hot isostatic pressing (HIP) A process that is generally used to reduce the porosity and increase the density of metal and ceramic materials during manufacturing, including the consolidation of metal powders and ceramic composites. HIPping has been selected as the means to stabilize and reduce the volume of high-level waste calcine, where calcined waste is retrieved, mixed with suitable additives, canistered, then heated and pressed in the container to form a ceramic-like material. The resulting waste form is expected to be equivalent to vitrified waste and potentially acceptable as a waste form for disposal in a geologic repository.

Idaho National Laboratory (INL) A science-based, applied engineering national laboratory located on an 890-square-mile complex in Southeastern Idaho that supports the U.S. Department of Energy's missions in nuclear and energy research, science, and national defense.

license An authorization issued by a regulatory body granting permission to perform specified activities related to a facility or an activity. The holder of a current license is termed a "licensee."

license application A document submitted to the Nuclear Regulatory Commission containing general information and a safety analysis for certain nuclear facilities such as a nuclear power plant, a geologic repository, or a spent-fuel storage facility. A license application must be approved before the facility is constructed and before it can be operated.

light water reactor A common type of thermal-neutron reactor that uses normal water, as opposed to heavy water, as both coolant and neutron moderator; a solid form of fissile elements is used as fuel.

lithophysae Cavities in silicic volcanic rock that are formed soon after the volcanic rocks are deposited because of the presence of vapors under very high pressure.

National Academy of Sciences (NAS) A private, non-profit society of distinguished scholars. Established by an Act of Congress in 1863, and charged with providing independent, objective advice to the nation on matters related to science and technology. Scientists are elected by their peers to membership in the NAS.

natural barriers Attributes of the earth that tend to isolate radionuclides from the human-accessible environment.

Nuclear Regulatory Commission (NRC) A federal agency headed by a five-member Commission, that formulates policies and regulations governing nuclear facilty and materials safety, issues orders to licensees, and adjudicates legal matters brought before it.

Nuclear Waste Assessment System for Technical Evaluation (NUWASTE) A computer-based, systems analysis tool developed by the U.S. NWTRB to evaluate the types and quantities of radioactive waste streams that would be generated by various fuel-cycle options considered by the U.S. Department of Energy.

Nuclear Waste Policy Act (NWPA) The federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission to develop a federal system for the management and geologic disposal of commercial spent nuclear fuel and other high-level radioactive wastes, as appropriate. The Act also specified other federal responsibilities for nuclear waste management, established the Nuclear Waste Fund to cover the costs of geologic disposal, and defined interactions between federal agencies and the states, local governments, and Native American Tribes.

Nuclear Waste Policy Amendments Act (NWPAA) The federal statute enacted in 1987 that amended the Nuclear Waste Policy Act by limiting repository site-characterization activities to Yucca Mountain, Nevada; establishing the Office of the Nuclear Waste Negotiator to seek a state or Native American Tribe willing to host a repository or monitored retrievable storage facility; creating the Nuclear Waste Technical Review Board; and increasing state and local government participation in the waste program.

Office of Civilian Radioactive Waste Management (OCRWM) An office in the U.S. Department of Energy established in the Nuclear Waste Policy Act to carry out the responsibilities of the Secretary of Energy under the Act.

Office of Environmental Management (DOE-EM) An Office in the U.S. Department of Energy with the mission of completing the safe cleanup of the environmental legacy of five decades of nuclear weapons development and government-sponsored nuclear energy research.

Office of Nuclear Energy (DOE-NE) An Office in the U.S. Department of Energy with the primary mission of advancing nuclear power as a resource capable of meeting the Nation's energy, environmental, and national security needs by resolving technical, cost, safety, proliferation resistance, and security barriers through research, development, and demonstration, as appropriate. When funding for the Office of Civilian Radioactive Waste Management was terminated in 2010, the Office of Nuclear Energy was assigned many of the responsibilities previously held by OCRWM for implementing the Nuclear Waste Policy Act.

Office of the Nuclear Waste Negotiator A federal agency created in the 1987 amendments to the Nuclear Waste Policy Act. The Negotiator was given authority by Congress to search the country for willing hosts for facilities to store or dispose of spent nuclear fuel and high-level radioactive waste. Funding for the agency was eliminated by Congress in 1995.

performance assessment An assessment of the performance of a system or subsystem and its implications for protection and safety at a planned or authorized facility. Differs from safety assessment in that it can be applied to parts of a facility, and it does not necessarily require assessment of radiological impacts.

Probabilistic Risk Analysis A simulation of the behavior of a system defined by parameters, events, and features whose values are represented by a statistical distribution. The analysis gives a corresponding distribution of results.

radiation source term The radiation "source term" sets the boundary condition for assessing the containment capability of the undisturbed geology in a repository system. Knowing the source term accurately is beneficial for properly assessing the performance of a repository and the potential radiation dose to the public.

radioactivity The spontaneous transformation of one radioisotope into one or more different isotopes (known as "decay products" or "daughter products"), accompanied by a decrease in radioactivity (compared to the parent material). This transformation takes place over a period of time (defined by the "half-life"), as a result of electron capture; fission; or the emission of alpha particles, beta particles, or photons (gamma radiation or x-rays) from the nucleus of an unstable atom. Each isotope in the sequence (known as a "decay chain") decays to the next until it forms a stable end product.

rail spur See **branch line**.

regulator An entity or a system of entities designated by the government of a nation as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby for regulating the siting, design, construction, commissioning, operation, closure, decommissioning, and, if required, subsequent institutional control of nuclear facilities or specific aspects of nuclear facilities.

research and development (R&D) Activities whose primary function is to discover and create new knowledge about scientific and technical topics.

safety assessment An assessment of the performance of an overall system and its impact, where the performance measure is radiological impact or some other measure of impact on safety.

safety case An integrated collection of arguments and evidence for demonstrating the safety of a facility. The safety case will typically include a safety assessment, but could also include independent lines of evidence and reasoning on the robustness and reliability of the safety assessment and the assumptions.

salt formation A geologic formation resulting from the evaporation of sea water. Salt formations occur as bedded or domal (salt dome) deposits. In a bedded formation, the salt formation is similar in shape to when it was deposited. A salt dome results from uplift within a bedded salt formation.

Savannah River Site (SRS) A 310-square-mile nuclear reservation located in the state of South Carolina, built during the 1950s to produce and process nuclear materials for deployment in nuclear weapons. The major focus of the site is cleanup of the nuclear activities previously undertaken there.

seismic Pertaining to an earthquake or earth vibration.

shale A consolidated clay rock that possesses closely spaced, well-defined layers.

s**odium-bearing waste (SBW)** A mixed hazardous, radioactive waste generated as a by-product of spent nuclear fuel reprocessing at the Idaho Nuclear Technology and Engineering Center on the Idaho National Laboratory site. The waste is composed primarily of decontamination solutions used over the years in support of operations, but includes small fractions of first-, second-, and third-cycle extraction wastes from fuel reprocessing. The acidic wastes are relatively high in sodium and potassium from the decontamination solutions, thus the name "sodium-bearing waste." Sodium-bearing waste is high in transuranics, but has significantly less fission product activity than calcine derived from first-cycle raffinate (waste solution).

spent nuclear fuel (SNF) Nuclear fuel removed from a reactor following irradiation that is not intended for further use in its present form because of depletion of fissile material, buildup of poison, or radiation or other damage.

thermal management strategy A plan for maintaining the temperatures of the waste form, the cooling system, the facility, and the natural and engineered barrier systems within design limits.

thermal pulse The period of approximately one thousand years immediately following repository closure during which temperatures on the waste package surface can rise to more than 150°C, according to the Department of Energy's repository design for Yucca Mountain.

thermomechanical analysis A technique used in thermal analysis, a branch of materials science, which studies the properties of materials as they change with temperature.

Total System Performance Assessment (TSPA) Term used by the U.S. Department of Energy to describe the particular performance assessments conducted to determine whether a Yucca Mountain repository would comply with the relevant regulatory requirements for waste isolation and containment and protection of human health.

transuranic (TRU) waste Waste defined in Title 40, Part 191 of the Code of Federal Regulations (Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes) as waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than 20 years, per gram of waste, except for: (1) high-level radioactive wastes; (2) wastes that the Department [of Energy] has determined, with the concurrence of the [EPA] Administrator, do not need the degree of isolation required by this part; or (3) wastes that the [Nuclear Regulatory] Commission has approved for disposal on a case-by-case basis in accordance with Title 10, Part 61 of the Code of Federal Regulations. Transuranic elements are artificially created in a reactor by irradiating uranium. These elements include neptunium, plutonium, americium, and curium. TRU waste results from reprocessing spent nuclear fuel to remove pluto-

nium-239 or other transuranic elements, and from fabricating nuclear weapons and plutonium-bearing reactor fuel. The waste may consist of plutonium-contaminated debris (such as worker clothing, tools, and equipment), sludge or liquid from reprocessing, or cuttings and scraps from machining plutonium.

tuff A rock composed of compacted volcanic ash.

underground research laboratory A facility where in situ testing can take place to stimulate repository operations and research aspects of potential repository performance.

vitrification The process of incorporating materials into a glass or glass-like form. Vitrification is commonly applied to the solidification of liquid high-level radioactive waste from the reprocessing of spent nuclear fuel.

volcanism The phenomenon of eruption of molten rock (magma) onto the surface of the Earth or a solid-surface planet or moon, where lava, pyroclastics, and volcanic gases erupt through a break in the surface called a vent. It includes all phenomena resulting from and causing magma within the crust or mantle of the body to rise through the crust and form volcanic rocks on the surface.

waste emplacement area Tunnels in which radioactive waste will be placed in a repository.

Waste Isolation Pilot Plant (WIPP) The U.S. Department of Energy's (DOE) Waste Isolation Pilot Plant (WIPP) is a deep geologic repository for permanent disposal of transuranic waste from the Nation's nuclear defense program. The waste consists of clothing, tools, rags, residues, debris, soil, and other items contaminated with small amounts of plutonium and other man-made radioactive elements.

waste package The waste material and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.

West Valley Demonstration Project (WVDP) The site of the first and (to date) only commercial reprocessing plant in the United States. The plant began operations in 1966 and shut down in 1972. The West Valley Demonstration Project Act of 1980 charged the U.S. Department of Energy with solidifying the high-level radioactive waste still at the site, disposing of the solidified waste, and decommissioning the facilities used in the process. However, the land and facilities are the property of the New York State Energy Research and Development Authority, not the Department of Energy. After DOE's responsibilities under the Act are completed, the Act requires that the site be returned to the state of New York.

References

Abkowitz, Mark. 2010. "Nuclear Waste Assessment System for Technical Evaluation (NUWASTE): Status and Initial Results." Presentation to the Blue Ribbon Commission on America's Nuclear Future (BRC), Subcommittee on Reactor and Fuel Cycle Technology. October 12, 2010.

Adkins, Harold E. 2012. "Modeling Used Fuel Storage Temperatures." Presentation to the U.S. Nuclear Waste Technical Review Board. October 17, 2012.

Birkholzer, Jens. 2011. "R&D Activities Supporting Disposal in Clay/Shale Repositories." Presentation to the U.S. Nuclear Waste Technical Review Board. September 13, 2011.

Blue Ribbon Commission on America's Nuclear Future (BRC). 2011a. Draft Report of the Blue Ribbon Commission on America's Nuclear Future, Subcommittee on Transportation and Storage. May 31, 2011.

———. 2011b. Draft Report of the Blue Ribbon Commission on America's Nuclear Future, Subcommittee on Disposal. June 1, 2011.

———. 2011c. Draft Report of the Blue Ribbon Commission on America's Nuclear Future, Subcommittee on Reactor and Fuel Cycle Technology. June 2011.

———. 2011d. Blue Ribbon Commission on America's Nuclear Future, Draft Report to the Secretary of Energy. July 29, 2011.

———. 2012. Blue Ribbon Commission on America's Nuclear Future, Report to the Secretary of Energy. January 2012.

Boyle, William. 2011. "R&D Activities for Used Nuclear Fuel Disposition: Storage, Transportation & Disposal." Presentation to the U.S. Nuclear Waste Technical Review Board. February 16, 2011.

Brady, Patrick V., et al. 2011. "Deep Borehole Disposal of Nuclear Waste." Presentation to the U.S. Nuclear Waste Technical Review Board. February 16, 2011.

Ewing, Rodney C. 2012a. December 11 letter from Rodney C. Ewing, Chairman, U.S. Nuclear Waste Technical Review Board, to David Huizenga, Senior Advisor for Environmental Management, U.S Department of Energy; "Comments on October Board meeting."

———. 2012b. December 11 letter from Rodney C. Ewing, Chairman, U.S. Nuclear Waste Technical Review Board, to Peter Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy; "Comments on October Board meeting."

Garrick, B. John. 2007. July 10 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on the Board's September workshop on localized corrosion."

———. 2008a. January 16 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on the September 19, 2007, Board meeting."

———. 2008b. April 22 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on the January Board meeting."

———. 2008c. Testimony of B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, before the Subcommittee on Energy and Air Quality, Committee on Energy and Commerce, U.S. House of Representatives. July 15, 2008.

———. 2008d. September 4 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on the May Board meeting."

———. 2008e. October 1 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on a September 18, 2008, letter from the Director."

———. 2008f. November 5 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on the September Board meeting."

———. 2009a. April 6 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Christopher A. Kouts, Acting Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy; "Comments on the January Board meeting."

———. 2009b. June 26 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to the Honorable Nancy Pelosi, Speaker of the U.S. House of Representatives; The Honorable Robert C. Byrd, President Pro Tempore of the U.S. Senate; and The Honorable Steven Chu, Secretary of the U.S. Department of Energy; "Comments on continuing the licensing process for a Yucca Mountain repository."

———. 2009c. August 13 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Steven Chu, Secretary, U.S. Department of Energy; "Comments on the Board's June meeting."

———. 2010a. October 16 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Warren F. Miller, Jr., Assistant Secretary for Nuclear Energy, U.S. Department of Energy; "Comments on the Board's June meeting."

———. 2010b. October 21 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Inés R. Triay, Assistant Secretary for Environmental Management, U.S. Department of Energy; "Comments on the June Board meeting."

———. 2010c. "Experience Gained on the Management and Disposition of High-Activity Waste." Presentation by B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to the Blue Ribbon Commission on America's Nuclear Future. November 16, 2010.

———. 2011a. June 30 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Chuck Hagel and Jonathan Lash, Co-Chairs, Subcommittee on Disposal, Blue Ribbon Commission on America's Nuclear Future; "Comments on Subcommitte's Draft Report."

———. 2011b. June 30 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Phil Sharp and Richard Meserve, Co-Chairs, Subcommittee on Transportation and Storage, Blue Ribbon Commission on America's Nuclear Future; "Comments on the Subcommittee's Draft Report."

———. 2011c. July 14 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Pete Domenici and Per F. Peterson, Co-Chairs, Subcommittee on Reactor and Fuel Cycle Technology, Blue Ribbon Commission on America's Nuclear Future; "Comments on the Subcommittee's Draft Report."

———. 2011d. July 26 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to David G. Huizenga, Acting Assistant Secretary for Environmental Management, U.S. Department of Energy; "Comments on April Board meeting."

———. 2011e. July 26 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Peter Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy; "Comments on the February and April Board meetings."

———. 2011f. October 31 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Lee H. Hamilton and Brent Scowcroft, Co-Chairs, Blue Ribbon Commission on America's Nuclear Future; "Comments on the Commission's Draft Report to the Secretary."

———. 2011g. December 8 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Monica Regalbuto, Deputy Assistant Secretary, Fuel Cycle Technologies, U.S. Department of Energy; "Comments on the Gap Analysis to Support Extended Storage of Used Nuclear Fuel, issued on June 30, 2011."

———. 2011h. December 30 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Peter B. Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy; "Comments on the September Board meeting."

———. 2012a. January 6 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Monica Regalbuto, Deputy Assistant Secretary, Fuel Cycle Technologies, U.S. Department of Energy; "Comments on a Management Proposal for Salt Disposal Investigations with a Field Scale Heater Test at WIPP, issued June 2011."

———. 2012b. March 28 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Peter Lyons, Assistant Secretary for Nuclear Energy, U.S. Department of Energy; "Comments on the January Board meeting."

———. 2012c. April 18 letter from B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board, to Steven Chu, Secretary, U.S. Department of Energy; "Comments on the final Report to the Secretary of the Blue Ribbon Commission on America's Nuclear Future."

Hardin, Ernest, et al. 2011. "Geologic Disposal Options in the USA." Presentation to the U.S. Nuclear Waste Technical Review Board. February 16, 2011.

———, et al. 2012a. "Generic Repository Concepts and Thermal Analysis." Presentation to the U.S. Nuclear Waste Technical Review Board. January 9, 2012.

———, et al. 2012b. "Generic Disposal Concepts and Thermal Load Management for Larger Waste Packages." Presentation to the U.S. Nuclear Waste Technical Review Board. October 17, 2012.

Kouts, Christopher A. 2009a. February 17 letter from Christopher A. Kouts, Acting Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board; "Comments on the Board's November 5, 2008, letter."

———. 2009b. June 1 letter from Christopher A. Kouts, Acting Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board; "Comments on the Board's April 6, 2009, letter."

Machiels, Albert J. and Wells, Alan H. 2009. "Direct Disposal of Dual-Purpose Canisters – Options for Assuring Criticality Control." Presentation to the U.S. Nuclear Waste Technical Review Board. January 28, 2009.

Metlay, Daniel S. 2010. "International Experience Developing Deep Geologic Repositories." Presentation to the Blue Ribbon Commission on America's Nuclear Future. July 7, 2010.

———. 2012. Testimony of Daniel S. Metlay, Senior Professional Staff, U.S. Nuclear Waste Technical Review Board, before the Subcommittee on Clean Air and Nuclear Safety, Committee on Environment and Public Works, U.S. Senate. June 7, 2012.

Nuclear Waste Technical Review Board (NWTRB). 2009a. Summer Board Meeting; June 11, 2009; Las Vegas, Nevada, (transcript of proceedings). Arlington, Virginia.

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

———. 2010a. Report to Congress and the Secretary, Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel. December 2010.

———. 2010b. Fall Board Meeting: October 26, 2010; Dulles, Virginia, (transcript of proceedings). Arlington, Virginia.

———. 2011. Winter Board Meeting: February 16, 2011; Las Vegas, Nevada, (transcript of proceedings). Arlington, Virginia.

Orrell, Andrew. 2011. "Deep Borehole Disposal: Programmatic Drivers and Pilot Demonstration Path Forward." Presentation to the U.S. Nuclear Waste Technical Review Board. February 16, 2011.

Parks, Edwin T. 2011. "Presentation to the U.S. Nuclear Waste Technical Review Board." September 13, 2011.

Regalbuto, Monica. 2011. "Update on the Fuel-Cycle Technology Activities of the U.S. Department of Energy's Office of Nuclear Energy (DOE-NE)." Presentation to the U.S. Nuclear Waste Technical Review Board. February 16, 2011.

———. 2012. "Fuel Cycle Research and Development." Presentation to the U.S. Nuclear Waste Technical Review Board. January 9, 2012.

Russell, Paige, et al. 2008. "Plans for Long-Term Corrosion Testing and Recent Results." Presentation to the U.S. Nuclear Waste Review Board. January 16, 2008.

Sproat, Edward F. III. 2008a. April 11 letter from Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board; "Comments on the Board's January 16 letter."

———. 2008b. September 18 letter from Edward F. Sproat III, Director, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, to B. John Garrick, Chairman, U.S. Nuclear Waste Technical Review Board: "Comments on the Board's September 4 letter."

Swift, Peter. 2011. "Basis for Identification of Disposal Options for Research and Development." Presentation to the U.S. Nuclear Waste Technical Review Board. September 13, 2011.

U.S. Congress. 1982. Nuclear Waste Policy Act of 1982 (NWPA). 97th Congress, 2nd Session. 1982. Washington, D.C. Government Printing Office.

———. 1987. Nuclear Waste Policy Amendments Act (NWPAA). Omnibus Budget Reconciliation Act of 1987. 100th Congress, 1st Session. 1987. Washington, D.C. Government Printing Office.

U.S. House of Representatives. 2011. Energy and Water Development Appropriations Bill, 2012. H. Rpt. 112-118. 112th Congress, 1st Session. Washington, D.C. Government Printing Office.

Wigeland, Roald. 2012. "Nuclear Energy System Evaluation and Screening." Presentation to the U.S. Nuclear Waste Technical Review Board. January 9, 2012.

Williams, Jeff. 2012. "Compatibility of Commercial Storage Containers with the Waste Management System." Presentation to the U.S. Nuclear Waste Technical Review Board. January 9, 2012.

10 CFR 63. "Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain Nevada." Code of Federal Regulations. Washington, D.C. Government Printing Office.

Appendices

A. Board Members

B. Board Strategic Plan

C. Board Publications

D. Board Testimony

E. Board Presentations and Letters to the BRC

F. Meetings of the Board

G. Board Correspondence with DOE