U.S. Nuclear Waste Technical Review Board

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

June 2015

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

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June 2015

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

June 10, 2015

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

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

The Honorable Ernest J. Moniz
Secretary
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Speaker Boehner, Senator Hatch, and Secretary Moniz:

The U.S. Nuclear Waste Technical Review Board was created by Congress in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) (Public Law 100-203) in order to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy to manage and dispose of high-level radioactive waste (HLW) and spent nuclear fuel (SNF). In accordance with provisions of the NWPAA directing the Board to report its findings, conclusions, and recommendations to Congress and the Secretary, the Board submits our report, *Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel*.

The Nuclear Waste Policy Act (NWPA) called for a Presidential decision about whether the development of a repository specifically for the disposal of radioactive waste resulting from activities related to the nuclear weapons complex was "required" and defined six factors to be considered in making such a decision. Based on an evaluation by the Department of Energy (DOE) of the need for a separate repository, President Ronald Reagan determined in 1985 that defense HLW should be disposed of in a repository with commercial SNF.

In an October 2014 report, *Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel*, DOE recommended disposal of some DOE-managed HLW and SNF in a separate geologic repository, including the possibility that small waste forms may be disposed of in deep boreholes. Subsequently, DOE completed a reevaluation of the need for a separate repository on the basis of the six factors identified in the

NWPA. The reevaluation was presented in DOE's *Report on Separate Disposal of Defense High-Level Radioactive Waste* released in March 2015. On March 24, 2015, President Barack Obama issued a Presidential Memorandum with a finding that "the development of a repository for the disposal of high-level radioactive waste resulting from atomic energy defense activities only is required."

Developing a separate repository for defense HLW represents a fundamental shift in policy for managing radioactive waste in the United States. Such a facility might also include defense SNF, depending on legal interpretations of DOE's authority under the Atomic Energy Act. Consequently, the Board has reviewed the two reports cited above, along with supporting studies prepared by DOE, and has identified a number of technical and scientific issues that should be addressed as DOE implements the new approach. Based on its review, the Board recommends that DOE:

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

The results of the Board's evaluation of the DOE reports and supporting studies, together with the basis for these recommendations, are presented in the attached report.

The Board will continue to evaluate and report to Congress and the Secretary on the technical and scientific validity of activities undertaken by DOE to implement the NWPA, including a program for developing a separate repository for defense waste based on the President's recent policy decision. As part of its continuing review, the Board will hold a public workshop on October 20–21, 2015, in Washington, D.C. on deep borehole disposal, which is one option discussed in DOE's October 2014 report for certain waste forms.

Sincerely,

Rodney C. Ewing
Chairman

U.S. Nuclear Waste Technical Review Board

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Executive Summary

The U.S. Nuclear Waste Technical Review Board (Board) was established as an independent federal agency in the 1987 Amendments to the Nuclear Waste Policy Act (NWPA). Congress charged the Board with "evaluating the technical and scientific validity" of activities undertaken by the Secretary of Energy related to the management and disposal of high-level radioactive waste (HLW) and spent nuclear fuel (SNF), and required the Board to report its findings, conclusions, and recommendations to Congress and the Secretary of Energy. In this document, the Board reviews recent reports by the Department of Energy (DOE) that address a proposed initiative to develop two mined, geologic repositories: one to dispose of defense HLW and possibly DOE-managed SNF, and the other to dispose of commercially generated HLW and SNF.

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

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

Developing a separate repository for defense HLW represents a fundamental shift in policy for managing radioactive waste in the United States. In addition, as DOE observed in the *Separate Disposal Report*, DOE retains its authority under the 1954 Atomic Energy Act to construct a repository that would be used exclusively to dispose of *both* defense HLW and SNF *as well as* for HLW and SNF from DOE's research and development activities. Although this authority may be open to conflicting legal interpretations, the Board's consideration of the technical and scientific questions that might arise if DOE pursues this new approach *presumes* that at least some DOE-managed SNF may be disposed of in a "defense-only" repository.

The Board identified a number of technical and scientific issues that should be addressed as DOE implements this new approach, including those related to waste form performance, DOE SNF degradation and release rates, repackaging of naval SNF for disposal, and disposal of DOE-managed HLW and SNF in deep boreholes.

Based on its review, the Board recommends that DOE:

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

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Background

The U.S. Nuclear Waste Technical Review Board (Board) was established as an independent federal agency in the 1987 Amendments to the Nuclear Waste Policy Act (NWPA). Congress charged the Board with "evaluating the technical and scientific validity" of activities undertaken by the Secretary of Energy related to the management and disposal of high-level radioactive waste (HLW) and spent nuclear fuel (SNF), and required the Board to report its findings, conclusions, and recommendations to Congress and the Secretary of Energy. In this document, the Board reviews recent reports by the Department of Energy (DOE) that address a proposed initiative to develop two mined, geologic repositories: one to dispose of defense HLW and possibly DOE-managed SNF, and the other to dispose of commercially generated HLW and SNF.

Congress passed the NWPA in 1982. The law created a process for siting, characterizing, licensing, and operating a mined, geologic repository for commercially generated HLW and SNF. However, Congress left open the question of whether HLW and SNF that originated in the nuclear weapons complex or that originated as part of U.S. Government research and development activities should be disposed of in the same repository as the HLW and SNF generated by commercial nuclear power plants. Specifically, Section 8(b)(1) of the NWPA requires that:

> Not later than 2 years after the date of the enactment of this Act, the President shall evaluate the use of disposal capacity at one or more repositories to be developed under subtitle A of title I for the disposal of high-level radioactive waste resulting from atomic energy defense activities.

That section identifies six factors that must be considered in the evaluation: cost efficiency, health and safety, regulation, transportation, public acceptability, and national security.

Further, Section 8(b)(2) of the NWPA provides that:

> Unless the President finds, after conducting the evaluation required in paragraph (1), that the development of a repository for the disposal of high-level radioactive waste resulting from atomic energy defense activities only is required, taking into account all of the factors described in such subsection, the Secretary shall proceed promptly with arrangement for the use of one or more of the repositories to be developed under subtitle A of title I for the disposal of such waste.

In 1985, President Ronald Reagan found "no basis to conclude that a defense-only repository is required," based on the legislatively mandated evaluation

(DOE, 1985) and a Memorandum from Secretary of Energy Donald Hodel (Hodel, 1985). As a result, the prevailing assumption of the U.S. nuclear waste management program has been that DOE-managed HLW and SNF would be commingled in the same disposal facility as commercial HLW[1] and SNF. Brief descriptions of commercial and DOE-managed HLW and SNF and their relative volumes and radioactivity are provided in Boxes 1 and 2 on the following pages.

In 2010, a series of events initiated new discussions about whether commercial and defense HLW and SNF should be commingled. That year, the Obama Administration concluded that the proposed repository at Yucca Mountain in Nevada was "unworkable," and it established the Blue Ribbon Commission on America's Nuclear Future (BRC) to make recommendations on a path forward for dealing with HLW and SNF. In January 2012, the BRC recommended that DOE revisit the commingling question and carry out a new evaluation under Section 8(b)(1) of the NWPA (BRC, 2012). In addition, in an April, 2012, Board letter to DOE that commented on the BRC's *Final Report* (Garrick, 2012), the Board noted that the issue of commingling waste "is a technical issue that deserves consideration" and recommended that "a technical study to determine whether to separate commercial spent fuel from defense and DOE wastes 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." DOE stated that it would study the issue in *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* (DOE, 2013), released in January 2013.

In October 2014, DOE issued, *Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel* (DOE, 2014a) (hereinafter *Assessment Report*). Based on an analysis of some of the technical issues involved, the *Assessment Report* recommended that DOE should pursue options for disposal of DOE-managed HLW from defense activities and some cooler DOE-managed SNF separately from commercial HLW and SNF. The *Assessment Report* also recommended the establishment of a focused research, development, and demonstration program to address the potential use of deep boreholes to dispose of smaller waste forms. Several months later, based on the considerations set forth in Section 8(b)(1) of the NWPA, DOE released a more formal evaluation, *Report on Separate Disposal of Defense High-Level Radioactive Waste* (DOE, 2015) (hereinafter *Separate Disposal Report*). Although this

[1] Commercial HLW comprises the highly radioactive material resulting from commercial fuel reprocessing that had been vitrified (immobilized in borosilicate glass) at the West Valley Demonstration Project (West Valley, New York). The vitrified waste form is stored at West Valley in 275 stainless steel canisters. The waste is owned by the State of New York and managed by DOE. Under the terms of the NWPA, it is not a candidate for disposal in a separate repository for DOE-managed wastes.

Box 1: Commercial Spent Nuclear Fuel and DOE-Managed Spent Nuclear Fuel and High-Level Radioactive Waste

Commercial spent nuclear fuel is discharged from commercial nuclear power plants when it is no longer useful for producing power. It is stored on-site in spent fuel pools or in dry storage casks that are either placed vertically on concrete pads or horizontally in concrete structures at what are termed Independent Spent Fuel Storage Installations (ISFSIs). ISFSIs are in operation at the majority of reactor sites, including 13 sites that no longer have operating reactors. Nearly all commercial SNF is composed of ceramic pellets of uranium dioxide sealed inside zirconium alloy metal tubes, referred to as cladding, to form fuel rods. Fuel rods are held in place by spacer grids in a geometric array called a fuel assembly.

DOE-managed SNF comprises a broad range of fuels, primarily from atomic energy defense activities (weapons plutonium production reactors and naval propulsion reactors). A smaller amount is from DOE research and development activities, domestic and foreign research reactors, and commercial sources. Some of the DOE-managed SNF is packaged into welded multicanister overpacks (MCOs), while the remainder is in storage and will require packaging into MCOs or other canisters prior to transport from the site where it is stored. DOE-managed SNF is much more heterogeneous than commercial SNF and has a variety of geometries, fuel matrices, cladding types, fissile materials, enrichments, and burnups.

High-level radioactive waste (HLW) is intensely radioactive material separated during the reprocessing of SNF. DOE-managed HLW mostly is the result of DOE's atomic energy defense activities and exists in several forms, including waste from SNF reprocessing that has already been vitrified (immobilized in borosilicate glass) or is planned to be vitrified; calcined HLW stored at the Idaho National Laboratory; and cesium and strontium in capsules stored at the Hanford site.

Figure 1 in this Box shows the relative volumes of commercial SNF (in 2012) and DOE-managed HLW and SNF, plus the additional commercial SNF projected to be discharged through 2048, the year DOE has set as its target for having a repository constructed and operating (DOE, 2013). From Figure 1, it is apparent that most of the waste in the inventory is commercial SNF; the volume of commercial SNF in 2012 is projected to double by 2048 due to the continued operation of nuclear power reactors.

Figure 2 in Box 2 shows the relative radioactivity of commercial SNF and DOE-managed HLW and SNF for the dates cited in the notes. Almost all the radioactivity is from commercial SNF and more than 95% of all the current radioactivity in each waste type is from radionuclides that have half-lives that are less than 50 years, primarily cesium-137 and strontium-90. The radioactivity will decrease with time. For example, the HLW radioactivity will decrease by about 20% in 10 years due to decay of cesium-137 and strontium-90, assuming no addition to the HLW inventory.

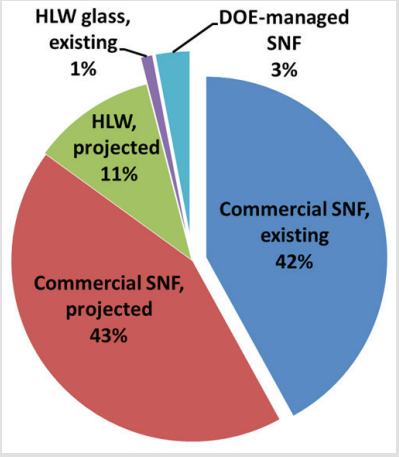

Figure 1. Relative Volumes of U.S. SNF and HLW, Existing and Projected, in 2048. Source: SNL (2014)

Note: Existing commercial SNF refers to commercial SNF existing as of 2012. The volume estimates presented in the SNL (2014) report are based on several assumptions, including (1) commercial nuclear power generation remains unchanged from today's rate and all commercial SNF is eventually packaged in dual-purpose canisters, (2) calcined HLW is processed by hot isostatic pressing, (3) sodium-bearing waste is treated by fluidized bed steam reforming, (4) sodium-bonded fuels undergo electrometallurgical treatment, and (5) all other waste forms are vitrified. Also, the volume of DOE-managed SNF shown in the figure includes approximately 3,500 m^3 [124,000 ft^3] of naval SNF that will be generated in the future.

Box 2: Commercial Spent Nuclear Fuel and DOE-Managed Spent Nuclear Fuel and High-Level Radioactive Waste (continued)

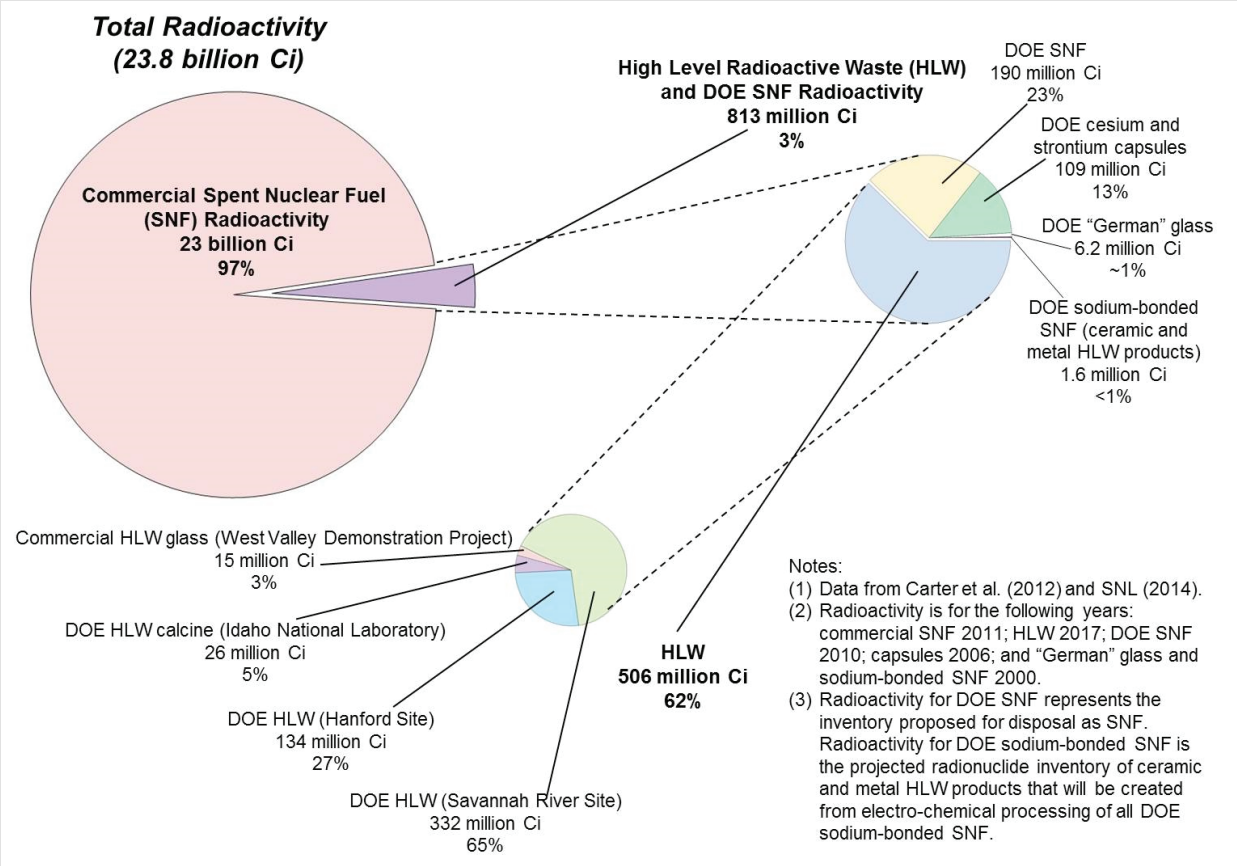

Figure 2. Relative Radioactivity of U.S. SNF and HLW

The SNF radioactivity (in Curies, Ci) is in the over 200,000 commercial SNF assemblies and in the ~200,000 pieces of DOE-managed SNF. The HLW radioactivity is in 1,335 cesium capsules, 601 strontium capsules, 34 canisters of glass created by DOE in the late 1980s for the German disposal program, and 275 glass canisters at West Valley, New York. DOE is vitrifying HLW at the Savannah River Site and plans to solidify into disposable waste forms the remaining HLW radioactivity. For clarity purposes, an additional ~550,000 Ci, in 2012, present in sodium-bearing waste at the Idaho National Laboratory (SNL, 2014) are not represented in the figure.

document is primarily an analysis to support a Presidential determination on whether to develop separate repositories, it also examines a set of associated technical issues. On March 24, 2015, President Barack Obama reversed President Reagan's action and issued a Presidential Memorandum that stated, "the development of a repository for the disposal of high-level radioactive waste resulting from atomic energy defense activities only is required."

Developing a repository for defense HLW and a second facility for commercial HLW and SNF represents a fundamental shift in what has been this country's

radioactive waste management policy for more than 30 years. President Obama's determination, moreover, potentially has ramifications that go beyond permitting the development of a separate defense HLW facility. As the *Separate Disposal Report* observed in an important footnote (DOE, 2015, page 2), DOE retains the authority under the 1954 Atomic Energy Act to construct a repository that would be used exclusively to dispose of *both* defense HLW and SNF *as well as* HLW and SNF from DOE's research and development activities. Although this authority may be open to conflicting legal interpretations, the Board's consideration of the technical and scientific questions that might arise if DOE pursues this new approach *presumes* that at least some DOE-managed SNF may be disposed of in a "defense-only" repository.

The Board's Technical Evaluation

In accordance with its mandate, the Board has reviewed the *Assessment Report* with the intent of identifying technical issues that DOE should address as it plans to develop a repository for other than-commercial HLW and SNF. In this review, the Board also considered how DOE's understanding of those issues evolved with the release of the 2015 *Separate Disposal Report*.

As a result of the Board's review of both the *Assessment Report and the Separate Disposal Report*, it has identified four technical areas that DOE should explore in greater depth. The following section of the document discusses those technical areas in detail. An understanding of the concepts of a mined, geologic repository and disposal in deep boreholes is important to this discussion. These are illustrated in Box 3 on the following page.

Performance of Repositories Developed in Different Host-Rock Types

The *Assessment Report* draws on a recent Sandia National Laboratories review of options for geologic disposal of HLW and SNF (SNL, 2014). This study summarizes the inventory of commercial and DOE-managed radioactive wastes requiring geologic disposal, and groups the inventory into waste groups with similar disposal characteristics. In the study, each waste group included both the waste itself and its associated packaging. The study qualitatively evaluated disposal options for each group of waste and concluded that all of the waste groups, except for the sodium-bonded fuel, potentially could be disposed of in any of the three host-rock types [salt, crystalline (e.g., granitic) rock, and clay/shale] being considered for a mined, geologic repository.

The Board questioned the conclusion that all of the waste groups could be disposed of in any of the host-rock types in its January 29, 2014, letter to DOE (Ewing, 2014). The DOE analysis was based on qualitative metrics and an evaluation of disposal performance that takes account of the combined

Box 3: Concepts of a Mined Geologic Repository and Disposal in Deep Boreholes

The concepts of a mined geologic repository and disposal in deep boreholes are compared in Figure 3. The KBS-3 concept developed for the proposed spent nuclear fuel (SNF) repository at Östhammar in Sweden (SKB, 2011) is depicted. In the KBS-3 concept, copper canisters with a ductile iron insert containing SNF [or possibly high-level radioactive waste (HLW)] are emplaced at a depth of approximately 500 m (~1,600 ft) in groundwater saturated crystalline (e.g., granitic) rock and surrounded by compacted bentonite clay buffer to restrict water flow around the canisters. As the repository is located at depth in a stable geologic environment, it is believed that the host rock provides long-term isolation of the waste from humans and the accessible environment. Additional waste isolation is provided by engineered barriers, including the welded copper canisters, the bentonite clay buffer, and the tunnel backfill material that limits water flow in the waste emplacement tunnels. In the view of the concept's originators, the low oxygen concentrations at repository depth ensure that the predicted corrosion rate of the copper canister will be small. Low oxygen concentrations also enhance the geochemical isolation of the waste because of the low solubility and limited mobility of many of the elements with long-lived radioisotopes, including plutonium and neptunium, that might be present in HLW and SNF.

Disposal in deep boreholes envisions placing wastes in canisters 0.30 m (12 inches) or less in diameter, and up to 4.2 m (166 inches) in length, in a deep borehole drilled into crystalline basement rock using commercially available technology (DOE, 2014a). The borehole would be drilled to a nominal depth of 5 km (3.1 miles) with a bottom-hole diameter of 0.43 m (17 inches). Small waste forms, such as cesium and strontium capsules, would be emplaced in the lower 2,000 m (~6,600 ft) of the borehole, and the upper 3,000 m (~9,800 ft) of the borehole would be sealed with alternating sections of concrete and compacted clay (DOE, 2014a). Long-term isolation of the waste is provided by the extremely low permeability of crystalline rocks at these depths (significantly deeper than for mined geologic repositories) and by the long pathway for diffusive transport upward through the borehole seal system. Similar to the KBS-3 repository concept, the low oxygen concentrations at depth enhance the geochemical isolation of the waste.

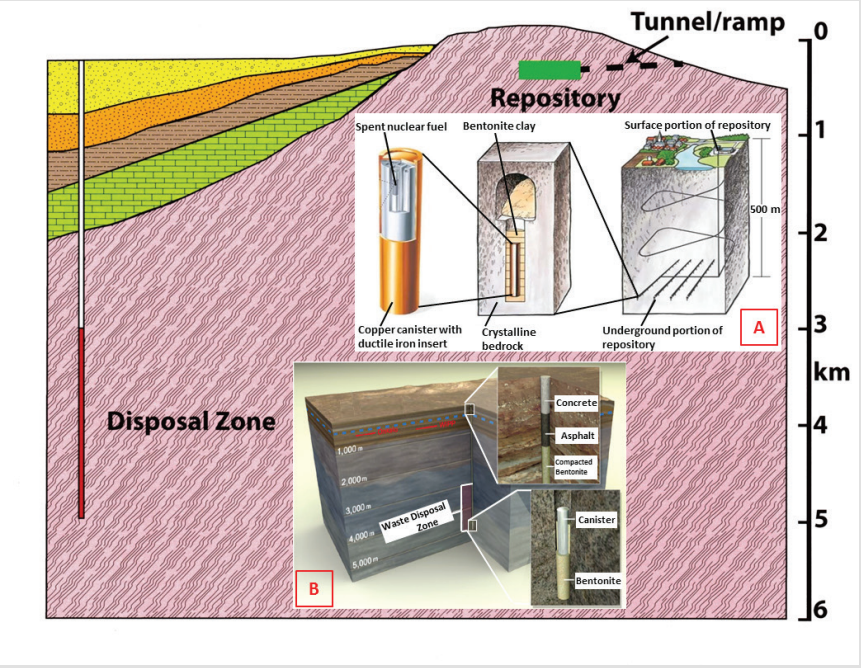

Figure 3. Comparison of the Concepts of a Mined Geologic Repository and Disposal in Deep Boreholes

Inset A illustrates details of the KBS-3 concept for a mined repository (SKB, 2011). Inset B depicts a concept for disposal in deep boreholes that includes asphalt seals and bentonite surrounding the canisters (Arnold *et al.*, 2011).

performance of the waste package and enclosed waste form. This analysis ends up primarily reflecting only the waste package performance. In the Board's view, DOE's implementation of a separate repository program for both defense HLW and SNF as well as SNF from DOE's research and development activities needs to be better informed by considering the performance of the waste form in the different potential host-rock types *after* degradation of the waste package. Much information can initially be obtained by looking at the performance of commercial SNF and vitrified HLW in different host-rock types. The analysis should take advantage of any relevant results from similar work in other countries.

Waste Form Characteristics

As Figure 2 in Box 2 suggests, in a mined geologic repository where DOE-managed and commercial HLW and SNF are commingled, the total radionuclide release from the repository would be dominated by the release from commercial SNF. For example, performance assessments of a Yucca Mountain repository indicated that radionuclide release from DOE HLW and SNF had little impact on the calculated dose because these waste forms comprised only about 3 percent of the radioactivity to be disposed of. For those performance assessments, DOE conservatively assumed the DOE SNF degrades instantaneously after the waste package is breached, whereas the expected degradation rates of commercial SNF were taken into account. In a repository for other-than-commercial HLW and SNF, vitrified HLW and DOE SNF will comprise about 62 and 23 percent, respectively, of the radioactivity to be disposed of, and most of the remainder will be from the cesium and strontium capsules. The characteristics of DOE-managed SNF are more varied than those of commercial SNF, and its degradation in repository environments is not as well understood as the degradation of commercial SNF or of vitrified HLW. For example, DOE SNF comes in several hundred varieties. For most of these fuel types, no known experimental data are available on the degradation and dissolution of the waste form in repository groundwaters (BSC, 2004). Further, some carbide-containing DOE fuel types can generate flammable gas when exposed to water and can lead to repository pressurization that potentially can affect the performance of a repository located in a saturated zone. Consequently, research on DOE-managed SNF degradation and radionuclide release rates is likely needed to support the safety analysis of a separate repository for DOE-managed HLW and SNF. If data on DOE-managed SNF degradation and radionuclide release rates were available, it would not be necessary to use the conservative assumption that the DOE SNF degrades instantaneously after the waste package is breached. Using realistic estimates of HLW and SNF degradation and radionuclide release could strengthen the basis for the safety assessment of a separate repository for DOE-managed HLW

and SNF. The Board will elaborate on issues related to DOE SNF as a waste form in a future report.

Research and Development Activities

Section 4.3 of the *Assessment Report* states that "all of the defense HLW and much of the DOE-managed SNF is relatively cool and could be emplaced in a wide range of repository concepts … without further aging or thermal load management considerations." The report asserts that no significant technological advances are needed to support a design and license application for a repository limited to defense HLW and most DOE-managed SNF that are compatible in size with any mined repository concept under consideration. At the same time, the report states that "cooler naval fuel that already has been placed into large canisters for storage and disposal … might require repackaging to be disposed of in repository concepts that rely on existing operational techniques for vertical hoist access to the repository" (DOE, 2014, page 23). However, Section 5 of the report, which describes research and development activities to address disposal of the full inventory of DOE-managed HLW and SNF, including naval SNF, does not identify the need for research and development activities to support repackaging of naval SNF for disposal, including the need for the design of a new waste package.

Disposal in Deep Boreholes

The *Assessment Report* relies on a Sandia National Laboratories study that proposes a reference design and general operational procedures for the disposal of HLW in deep boreholes (Arnold et al., 2011). The Board noted that there are technical challenges associated with the disposal of HLW and SNF in deep boreholes in its July 30, 2013, letter to DOE (Ewing, 2013). These technical challenges, also discussed in the Board's factsheet on *Deep Borehole Disposal of Spent Nuclear Fuel and High-Level Waste* (http://www.nwtrb.gov/facts/deepborehole.pdf), include:

- characterization at depth
- drilling technology
- casing and sealing technology
- emplacement of waste packages
- effectiveness of borehole seals
- retrieval of emplaced wastes

The *Assessment Report* does not present information about the time that might be required to develop the technology for drilling, emplacing, and retrieving waste in deep boreholes. DOE plans to conduct a deep borehole field test (DOE, 2014b), which may begin to address some, but not all, of the technical challenges of deep borehole disposal.

The *Assessment Report* only identifies size as the basis for determining which DOE-managed waste forms would be candidates for disposal in deep boreholes drilled using currently available commercial drilling technology. While the Board recognizes that size is a qualifying factor in determining which waste forms could be emplaced in deep boreholes, there are additional important factors that must be considered. These factors include the degradation rates of the waste form and engineered barriers and the half life, geochemical mobility, and heat production of radionuclides present in the proposed waste forms. The required robustness of the waste package that would allow waste retrieval and the compatibility of the waste package with the waste form also should be considered. Together with the time frame that might be required for deep borehole technology development and deployment, these factors could provide a basis for determining whether or not disposal of DOE-managed HLW and SNF in deep boreholes warrants the significant effort that would be required.

As an example, the half-lives of cesium-137 and strontium-90 are relatively short (~30 years) in the context of the time periods required for repository performance. These are the primary radionuclides, present in the form of cesium chloride and strontium fluoride respectively, that exist inside double-walled capsules stored at the Hanford site. Cesium-137 and strontium-90 and their decay products generate a significant amount of heat. Cesium chloride is a highly soluble material. Although cesium-135 has a much longer half-life (2 million years) than cesium-137, the cesium-135 concentration in the capsules is low and the geochemical mobility of cesium is limited due to sorption processes if disposed of in an appropriate geologic environment, whether in mined geologic repositories or in deep boreholes. Thus, cesium-135 release to the accessible environment likely can be shown to meet regulatory requirements. It is not evident that deep boreholes are a necessary disposal pathway for cesium and strontium capsules, given that other geologic disposal concepts may also be suitable for cesium and strontium, either due to the relatively short half-lives or the limited geochemical mobility of their radioisotopes.

As noted in the *Assessment Report*, DOE's waste isolation strategy for disposal in deep boreholes relies primarily on the geology, the depth of burial, and a long-lived borehole seal system, with little long-term performance required of the waste package. However, once the geochemical mobility and other factors related to long-term performance are well-understood, it may become evident that robust multiple barriers are needed to protect the public and the environment. Thus, the Board suggests that DOE improve the safety case for the deep borehole concept by placing additional emphasis on engineered barriers to further limit the release of radionuclides from the high solubility waste forms (e.g., cesium chloride salts in capsules) under consideration. The enhancement of the safety case should include the use of robust waste packages

that would allow retrieval in the event of problems being encountered during emplacement. Further, given that the DOE waste isolation strategy relies heavily on the performance of the borehole seal system, the Board suggests that a research program on sealing technology should be part of the DOE strategy, particularly when disposing of very thermally hot waste, such as the cesium and strontium capsules.

Additional Comments

The comments above focus specifically on the major technical questions that the *Assessment Report* has not fully evaluated. The Board would be remiss, however, if it did not at least mention additional issues.

Potentially Negative Outcomes of the Options Considered

The *Assessment Report* does not present or discuss any of the potentially negative outcomes or consequences associated with each of the options. One potentially negative outcome that DOE did not consider relates to repository thermal management. If cooler DOE-managed HLW and SNF are disposed of in a separate repository, that strategy would eliminate the flexibility of managing commercial SNF repository thermal conditions by emplacing cooler DOE-managed HLW and SNF between hotter commercial SNF packages.

Another important outcome relates to how DOE determines public acceptability. The report maintains that acceptability for interested and affected parties in communities and states currently storing DOE-managed HLW and SNF might be increased if separate repositories were developed. However, the report does not consider how public acceptability by other important parties, such as the owners of commercial SNF and the communities around the nuclear plant sites, might be decreased if these stakeholders perceive that construction of a repository for DOE-managed waste is causing delays or is diverting significant resources from construction of a repository for commercial waste. In addition, the *Assessment Report* suggests that attempting to site a defense waste only repository would not produce as much public opposition as siting a repository where commercial HLW and SNF would be disposed, although it offers no direct evidence to support that claim.

Phased, Adaptive, and Consent-Based Approach

The *Assessment Report* devotes considerable attention to the importance of a phased, adaptive, and consent-based approach to repository siting. It claims, "a stepwise and staged approach of proceeding first with the easiest waste to transport and dispose of will help to develop the public confidence that is essential to a successful waste management program" (DOE, 2014, page 25). However, it is not clear how experience in the transport and disposal of DOE-

managed wastes, which have lower thermal output, lower total radioactivity, and, for HLW, little fissile content, would contribute to greater public confidence with respect to the transportation and disposal of other wastes, including commercial SNF, which have higher thermal output, radioactivity, and fissile content.

The *Assessment Report* cites the National Research Council's publication, *One Step at a Time: The Staged Development of Geologic Repositories for High-Level Radioactive Waste* (National Research Council, 2003). A principal tenet of that document is that the repository development process should be staged and flexible, allowing the implementer to respond to new information and circumstances. The National Research Council report examines the organizational requirements needed to implement a staged and adaptive process, some of which are difficult to effectively implement (e.g., institutional constancy as well as faithful adherence to the mission and its imperatives over the long-term). In light of previous experience of trying to develop a mined geologic repository for HLW and SNF in the United States, the assertion that a staged approach will help develop public confidence might be better supported if it had considered how DOE might meet these challenging requirements.

Cost Differences Between Developing a Common Repository and Developing Two Separate Repositories

The *Assessment Report* states that it could cost less to develop a single repository than to develop two separate repositories. At the same time, it asserts that a common repository may be the least cost-effective option *if* costs associated with other factors, such as the need to safely store immobilized tank waste, are considered. DOE does not present the basis for this assertion. The cost information contained in the report indicates that the estimated cost of two separate repositories could be substantially higher than the cost of a single repository. DOE's estimates range from ~$39 billion to ~$131 billion for development of separate repositories, depending on the geologic host rock selected. The estimates range from ~$29 billion to ~$96 billion for development of a common repository (DOE, 2014a; Table 3). Also, the *Assessment Report* does not include siting costs in the estimates that it provides. The significantly higher cost of two repositories as compared with one repository could very well be even higher if the siting costs are included in the cost estimate. The conclusion that a single, common repository could be the least cost-effective option, cannot be justified without greater specificity about the offsetting savings, especially given the magnitude of the reported differences in total costs.

DOE'S Analyses in the Separate Disposal Report

The *Separate Disposal Report* addresses some of the gaps contained in the *Assessment Report*. For example, DOE provides a more detailed description of the offsetting savings associated with developing a separate repository for defense HLW, although it still does not provide quantitative estimates of those savings. DOE also argues that a defense HLW repository might be constructed in a host-rock formation that is less expensive to develop compared to a repository that would dispose of all waste forms. However, the *Separate Disposal Report* still does not answer many of the important technical questions that were noted above.

In the Board's view, the *Separate Disposal Report* presents additional arguments that are not in agreement with positions DOE previously reached. For example, although shipment of defense HLW could be done by truck, the technical basis to support a preference for truck transport over rail transport is not provided in the *Separate Disposal Report*. In a Record of Decision (ROD) from 2004, DOE concluded that it should use mostly rail as the transportation mode for HLW and SNF, because "using mostly rail tends to minimize the potential environmental impacts that could occur" and also would "result in fewer potential traffic fatalities and, under routine conditions, slightly fewer latent cancer fatalities to workers and the general public relative to mostly legal-weight truck shipments" (DOE, 2004). Although this ROD was issued in the context of the development of a repository at Yucca Mountain, the safety and environmental considerations on which it was based would apply to the transportation of HLW and SNF to any repository.

In addition, the *Separate Disposal Report* states "[t]he development of a Defense HLW Repository would provide an early opportunity to develop and exercise institutional procedures specific to transportation" and enable DOE to "build on its track record of safely transporting nuclear waste" (DOE, 2015, page 16). The Board acknowledges that starting with a defense HLW repository allows institutional procedures (e.g., regulatory approvals and notifications, emergency preparedness, communication plans) specific to transportation to be developed and tested. However, in the Board's view, lessons on technical safety issues that are learned from transporting defense HLW by truck may not be entirely applicable to transporting commercial SNF by rail. The HLW to be transported from DOE sites for repository disposal is in the form of glass that was poured in a molten state into stainless steel canisters and allowed to solidify. By comparison, commercial SNF is in the form of uranium oxide pellets in long metal tubes, referred to as cladding, made of a zirconium alloy that may be embrittled from irradiation in a reactor followed by extended storage. Consequently, HLW and SNF have quite different characteristics and

are subject to different degradation and damage mechanisms before and during transportation.

Recommendations

President Obama has determined that a separate repository for defense HLW is "required" under the provisions of Section 8 of the NWPA. Two DOE analyses provide the technical bases supporting that determination and the technical foundation for implementation of the policy. However, the two DOE reports do not fully identify the technical issues that need to be considered as plans and technology are developed to implement this new approach for the long-term management of this country's HLW and SNF. Based on its review, the Board recommends that DOE:

1) Consider waste form performance in different host-rock types after degradation of the waste package in future assessments. Much information can initially be obtained by looking at the performance of commercial SNF and vitrified HLW in different host-rock types.

2) Develop a better understanding of the degradation rates of DOE SNF in potential repository geologic environments, particularly the DOE SNF types that could contribute most to radionuclide release and calculated dose, to improve the basis for the separate repository safety assessment.

3) Evaluate approaches, benefits, and costs of repackaging cooler naval SNF into smaller disposal packages.

4) Conduct research on borehole sealing technology and assess whether more robust engineered barriers might be required for disposing of selected waste forms in deep boreholes.

As DOE proceeds with its plans for a separate defense-waste only and commercial repositories, the Board looks forward to reviewing the related key technical assessments and evaluations prepared by the Department.

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