U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE IN THE UNITED STATES

OVERVIEW

The two main types of spent nuclear fuel (SNF) stored in the United States are commercial SNF and U.S. Department of Energy (DOE)-managed SNF. High-level radioactive waste (HLW), which is the product of chemically reprocessing[1] SNF, can be processed or unprocessed. The processing[2] is used to produce a more stable HLW form that can be transported and eventually disposed of in a geologic repository. The three main types of processed HLW, all managed by DOE, are vitrified (immobilized in borosilicate glass) HLW, calcined waste, and cesium and strontium capsules. A great portion of HLW remains unprocessed and stored in underground tanks, but will be processed in the future. Hyperlinks to fact sheets describing the main types of SNF and HLW are included below.

Figure 1 shows a comparison of the estimated relative volumes of different waste forms requiring geologic disposal based on the existing SNF and HLW inventory and on the inventory projected through

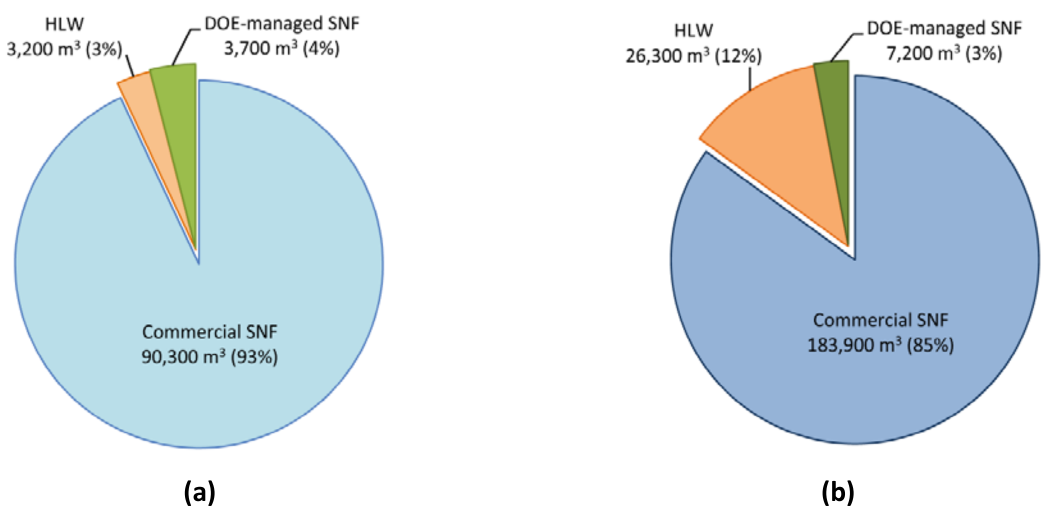

Figure 1. Estimated Relative Volumes of Different Waste Forms Requiring Geologic Disposal Based on the Inventory of (a) Existing and (b) Projected (in 2048) U.S. SNF and HLW.

Note: Data from SNL (2014). The estimated volumes of waste forms presented in the SNL (2014) report and shown in the figure are based on several assumptions, including (1) existing commercial SNF refers to commercial SNF existing as of 2012, (2) commercial nuclear power generation remains unchanged from today's rate and all commercial SNF is eventually packaged in dual-purpose canisters, (3) sodium-bonded fuels undergo electrometallurgical treatment, (4) sodium-bearing waste is treated by fluidized bed steam reforming, (5) calcined HLW is processed by hot isostatic pressing with additives, and (6) all other HLW (including the cesium and strontium capsules) is vitrified. Much of the existing HLW remains unprocessed and stored in underground tanks, ~140,000 m^3 at the Savannah River Site and ~210,000 m^3 at the Hanford Site (see fact sheet on Vitrified HLW).

---

[1]A process or operation to extract radioactive isotopes from SNF for further use or to separate out various waste streams.

[2]A process or operation to treat SNF to create HLW forms that can be transported and disposed of without separating the fissile material for weapons use.

2048, which is the year DOE has set as its target for having a geologic repository for SNF and HLW constructed and operating (DOE, 2013). As Figure 1 depicts, the waste forms requiring geologic disposal based on existing SNF and HLW inventory are mostly commercial SNF. In future years, the volume of commercial SNF will continue to dominate that of other waste forms requiring geologic disposal because of the continued operation of nuclear power reactors. The commercial SNF waste form volume is projected to double by 2048.

Figure 2 shows the estimated relative radioactivity of commercial SNF and DOE-managed SNF and HLW. Almost all the radioactivity comes from commercial SNF. More than 95% of the radioactivity associated with each waste type comes from radionuclides with half-lives of less than 50 years, primarily cesium-137 and strontium-90. The HLW radioactivity depicted in Figure 2 will decrease by about 20% in 10 years due to decay of cesium-137 and strontium-90.

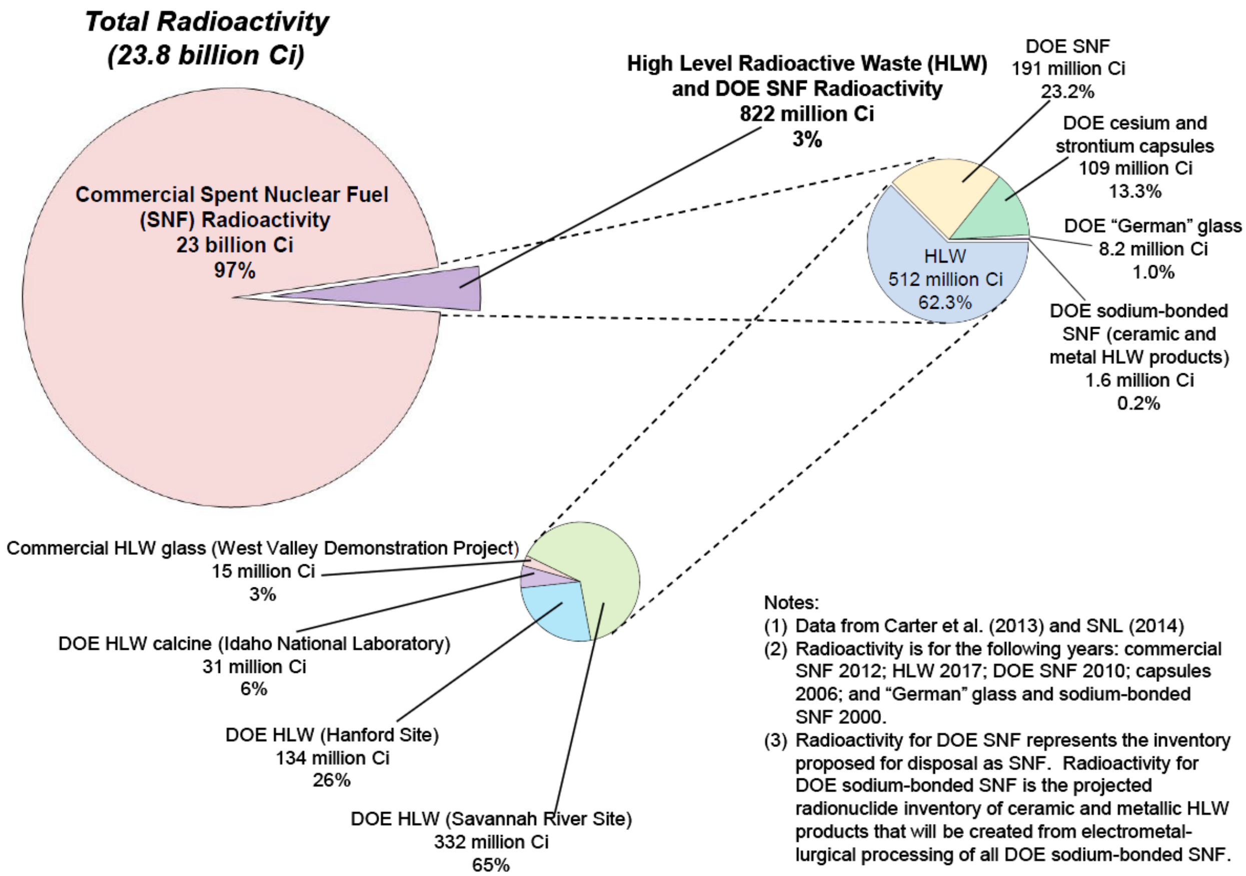

Figure 2. Relative Radioactivity of U.S. SNF and HLW[3]

---

[3]Figure modified from NWTRB (2016a). The radioactivity emitted by SNF (in Curies, Ci) comes from the more than 200,000 existing commercial SNF assemblies and the ~200,000 pieces of DOE-managed SNF. The radioactivity emitted by HLW comes from the 1,335 cesium capsules, 601 strontium capsules, and 34 canisters of glass created by DOE in the late 1980s in support of the HLW disposal program in Germany; 275 glass canisters at West Valley, New York; the ~4,000 canisters of vitrified HLW (as of 2015) at the Savannah River Site (SRS); and the unprocessed HLW currently stored as a liquid in underground tanks at SRS and the Hanford Site. DOE is vitrifying HLW at SRS and plans to solidify the remaining unprocessed HLW at SRS and the Hanford Site into disposable waste forms.

CATEGORIES OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE IN THE UNITED STATES

Commercial SNF, resulting from commercial nuclear power production, is composed of ceramic pellets of uranium dioxide sealed inside mainly zirconium alloy metal cladding. SNF removed from nuclear power plants is stored on-site in water-filled spent fuel pools, as well as in dry storage systems at Independent Spent Fuel Storage Installations (ISFSIs). The majority of reactor sites have ISFSIs.

DOE-managed SNF comprises a broad range of fuels, mostly from defense-related nuclear activities (primarily, weapons plutonium production reactors and naval propulsion reactors). DOE-managed SNF has a variety of geometries, fuel matrices, cladding types, fissile materials, enrichments, and burnups; thus, it is much more heterogeneous than commercial SNF.

Vitrified HLW has been solidified in borosilicate glass inside stainless steel canisters. DOE plans to vitrify much of the unprocessed HLW that remains stored in underground tanks.

Calcined HLW is a fine, granular material that results from drying and thermally decomposing HLW at high temperatures. Liquid HLW was calcined at the Idaho National Laboratory (INL), near Idaho Falls, Idaho, as an alternative to vitrification and is currently stored on-site in stainless steel silos referred to as "storage bins" in a custom-built facility at INL.

Cesium and strontium capsules, another type of HLW, were fabricated and stored at the Hanford Site, near Hanford, Washington, to reduce the heat load of the HLW stored in underground tanks at the site. The capsules contain highly radioactive, but relatively short-lived, cesium-137 and strontium-90. The capsules are stored underwater in pools lined with stainless steel to cool the capsules and to shield personnel and equipment from the radiation emitted by the capsules.

DISPOSAL OPTIONS

The intended method for providing long-term isolation of SNF and HLW in the United States and most other countries is mined geologic disposal. Until recently, the plan in the United States was to "commingle" DOE-managed SNF and HLW with commercial SNF in a single repository. However, in March 2015, DOE announced that it would move forward with planning for a disposal strategy that includes disposal of some DOE-managed HLW, and perhaps some DOE-managed SNF, separately from commercial SNF. Disposal in deep boreholes is also an option being investigated for some "smaller" forms of HLW.

Figure 3 compares the concepts of a mined geologic repository and disposal in deep boreholes. The KBS-3 concept developed for a proposed SNF repository in Sweden (SKB, 2011) is depicted. In the KBS-3 concept, copper canisters containing SNF are emplaced at a depth of approximately 500 m (~1,600 ft) in groundwater-saturated crystalline (*e.g.*, granitic) rock, surrounded by a compacted bentonite clay buffer to restrict water flow around the canisters and slow the movement of radionuclides. In the view of the concept's originators, the host rock will provide long-term isolation of the waste from humans and the accessible environment (SKB, 2011). The low oxygen concentrations at repository depths also will inhibit corrosion of the waste canister and limit the solubility of some radionuclides and their transport from the site.

The concept of disposal in deep boreholes envisions placing radioactive waste forms in deep boreholes drilled into crystalline basement rock (NWTRB, 2016b). In the view of the concept's proponents, the extremely low permeability of crystalline rocks and the long pathway for diffusive transport of radionuclides to sources of drinking water will provide long-term isolation of the waste. Similar to the KBS-3 repository concept, the low oxygen concentrations enhance the geochemical isolation of the waste. In the deep borehole disposal concept DOE is developing (DOE, 2014), boreholes would be drilled to a

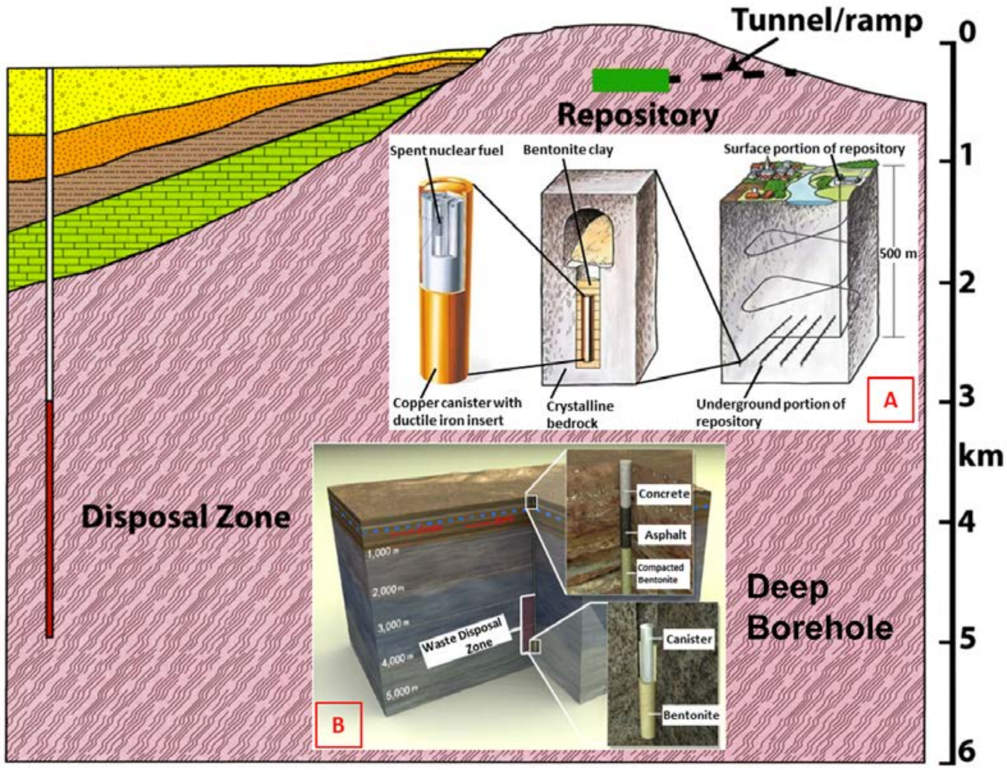

Figure 3. Comparison of the Concepts of a Mined Geologic Repository and Disposal in Deep Boreholes

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

nominal depth of 5 km (3.1 mi) with a bottom-hole diameter of 0.43 m (17 in). Small waste forms, such as cesium and strontium capsules, would be emplaced in the lower 2,000 m (~6,600 ft) of a borehole, and the upper 3,000 m (~9,800 ft) would be sealed with alternating sections of concrete and compacted clay (Arnold *et al.*, 2011; DOE, 2014). Asphalt also may be used in the shallow portion of the borehole seal system (Arnold *et al*., 2011).

REFERENCES

Arnold, B.W., P.V. Brady, S.J. Bauer, C. Herrick, S. Pye, and J. Finger. (2011). *Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste*. SAND2011-6749. Albuquerque, NM: Sandia National Laboratories.

Carter, J.T., A.J. Luptak, J. Gastelum, C. Stockman, and A. Miller. (2013). *Fuel Cycle Potential Waste Inventory for Disposition*. DOE Publication No. FCR&D-USED-2010-000031, Rev 6. Washington, D.C.: U.S. Department of Energy.

DOE (Department of Energy). (2013). *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*. Washington, D.C.: U.S. Department of Energy.

DOE. (2014). *Assessment of Disposal Options for DOE-Managed High-Level Radioactive Waste and Spent Nuclear Fuel*. Washington, D.C.: U.S. Department of Energy.

NWTRB (Nuclear Waste Technical Review Board). (2016a). *Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel*. Arlington, VA: U.S. Nuclear Waste Technical Review Board. Report in preparation.

NWTRB. (2016b). *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program*. Arlington, VA: U.S. Nuclear Waste Technical Review Board.

SKB (Swedish Nuclear Fuel and Waste Management Company). (2011). *Long-Term Safety for the Final Repository for Spent Nuclear Fuel at Forsmark*. TR-11-01. Stockholm, Sweden: Swedish Nuclear Fuel and Waste Management Company.

SNL (Sandia National Laboratories). (2014). *Evaluation of Options for Permanent Geologic Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste in Support of a Comprehensive National Nuclear Fuel Cycle Strategy*, Volume I and II (Appendices). SAND2014-0187P (Vol. 1), SAND2014-0189P (Vol. II). Albuquerque, NM: Sandia National Laboratories

The U.S. Nuclear Waste Technical Review Board is an independent federal agency established in the 1987 amendments to the Nuclear Waste Policy Act (NWPA). The Board evaluates the technical and scientific validity of U.S. Department of Energy activities related to implementing the NWPA and provides objective expert advice on nuclear waste issues to Congress and the Secretary of Energy. The eleven Board members are nominated by the National Academy of Sciences and are appointed by the President.