



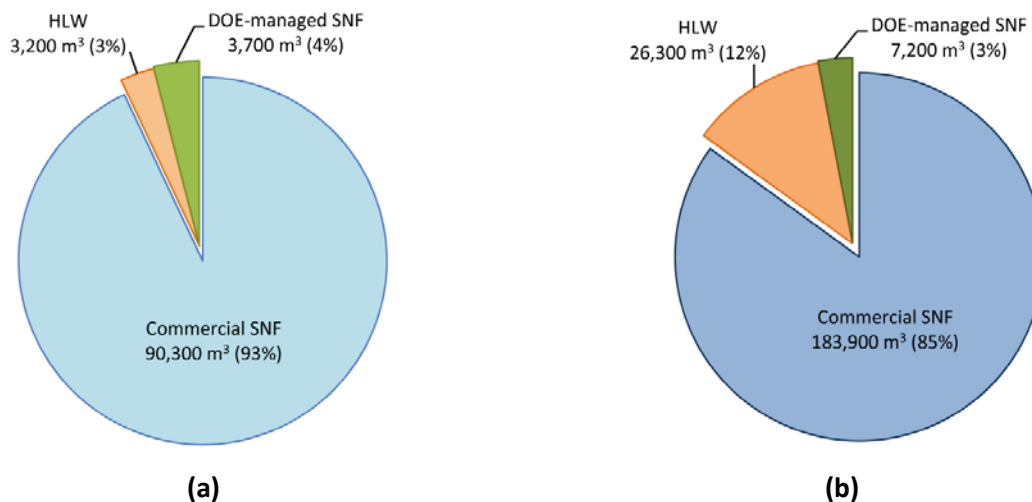
## U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

# 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<sup>1</sup> SNF, can be processed or unprocessed. The processing<sup>2</sup> 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.**

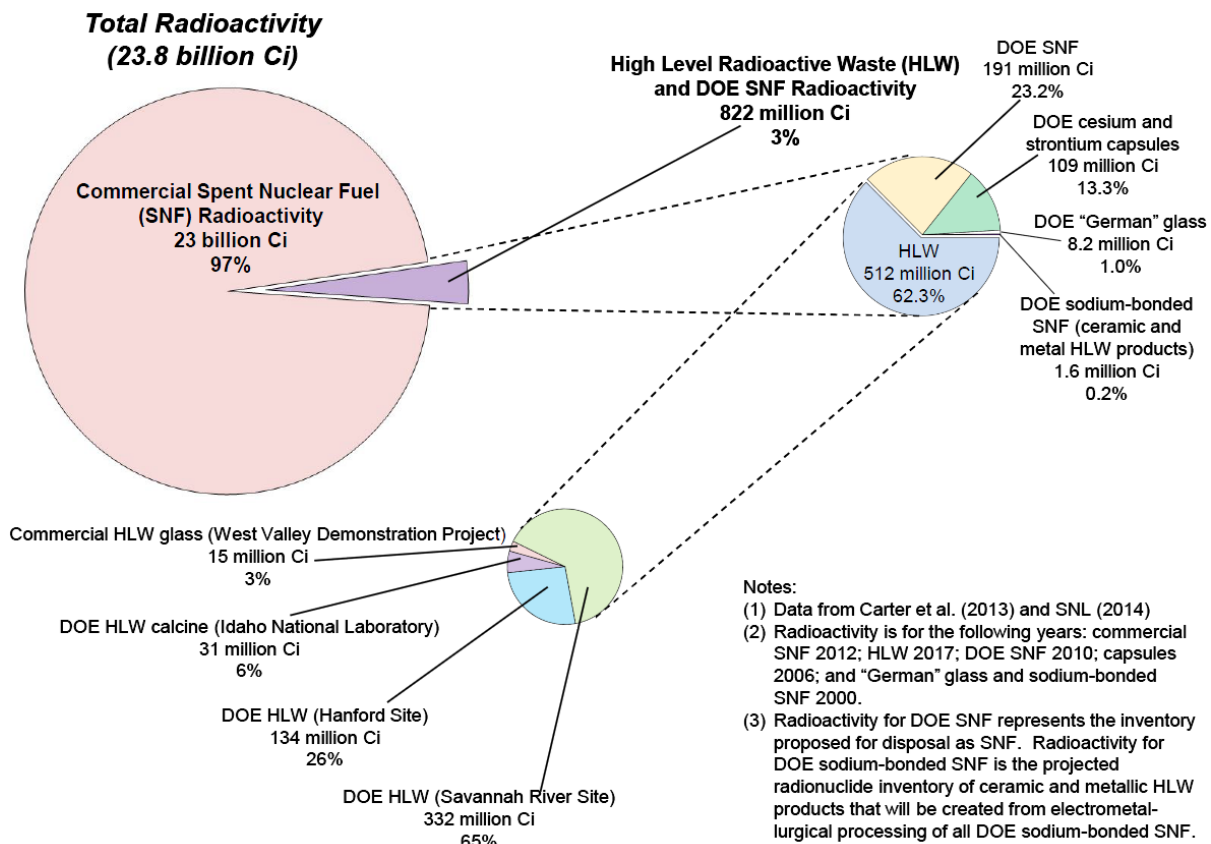
Note: Data from SNL (2014). The estimated volumes of waste forms presented in the SNL (2014) report and shown in the figure are based on several assumptions, including (1) existing commercial SNF refers to commercial SNF existing as of 2012, (2) commercial nuclear power generation remains unchanged from 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, ~136,000 m<sup>3</sup> at the Savannah River Site and ~210,000 m<sup>3</sup> at the Hanford Site (see fact sheet on [Vitrified HLW](#)).

<sup>1</sup> A process or operation to extract radioactive isotopes from SNF for further use or to separate out various waste streams.

<sup>2</sup> 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. 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.<sup>3</sup>**

<sup>3</sup> Figure modified from NWTRB (2017). The radioactivity emitted by SNF (in curies, Ci) comes from the more than 270,000 existing commercial SNF assemblies [as of December 2017 (Vinson and Metzger 2017)] 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 HLW glass canisters at West Valley, New York; the ~4,000 canisters of vitrified HLW [as of January 2016 (Chew and Hamm 2016)] 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. The DOE SNF value does not include naval SNF. For clarity purposes, an additional ~550,000 Ci, in 2012, present in sodium-bearing waste at the Idaho National Laboratory (SNL 2014) are not depicted in the figure.

## 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<sup>4</sup>; 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. The cesium and strontium were removed from the HLW in underground storage tanks at Hanford to reduce the heat load in the tanks. 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.

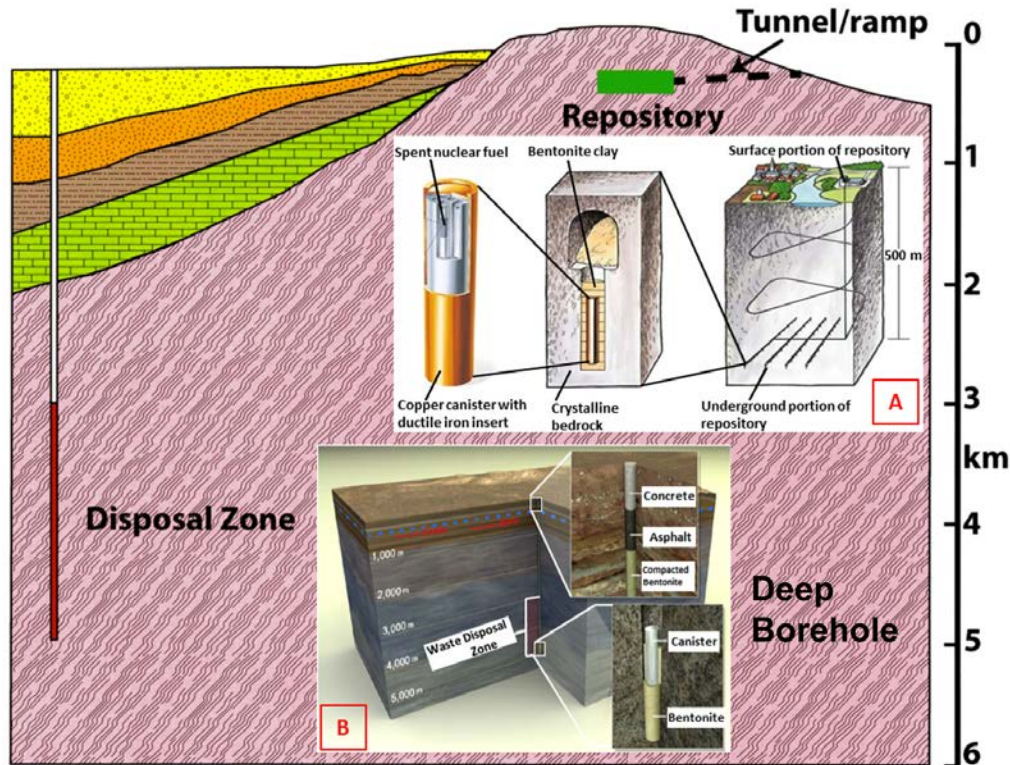
### DISPOSAL OPTIONS

The intended method for providing long-term isolation of SNF and HLW in the United States and most other countries is mined geologic disposal. The plan in the United States is to “commingle” DOE-managed SNF and HLW with commercial SNF in a single repository. However, DOE recently considered a 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 DOE contemplated 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.

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<sup>4</sup> Burnup is the amount of energy extracted per unit mass of the fuel. Typical units for burnup are gigawatt-days per metric ton of uranium originally contained in the fuel (GWd/MTU) or megawatt-days per metric ton of uranium (MWd/MTU).



**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).

The concept of disposal in deep boreholes envisions placing radioactive waste forms in deep boreholes drilled into crystalline basement rock (NWTRB 2016). 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, boreholes would be drilled to a 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).

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**The U.S. Nuclear Waste Technical Review Board** is an

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