



U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

DOE-MANAGED SPENT NUCLEAR FUEL

OVERVIEW

U.S. Department of Energy (DOE)-managed spent nuclear fuel (SNF) comprises a broad range of fuels, resulting mostly (85% by mass) from defense-related nuclear activities (primarily, 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.

STORAGE AND LOCATION

Nearly all DOE-managed SNF is stored at four locations: the Hanford Site in Washington State, the Idaho National Laboratory in Idaho, the Savannah River Site in South Carolina, and the Fort St. Vrain Independent Spent Fuel Storage Installation in Colorado. Approximately 2,500 metric tons of heavy metal (MTHM)¹ of DOE-managed SNF are stored at those sites as of January 2013 (NWTRB, 2016). A small amount (~10 MTHM) is stored at over 30 other domestic locations. Figure 1 shows the four major storage locations and the total mass of DOE-managed SNF at each of those locations.

About 98% by mass of the DOE-managed SNF is in dry storage, mostly at the Hanford Site inside multiccanister overpacks (MCOs), which are welded stainless steel canisters designed for storage, transportation, and eventual disposal of the Hanford N Reactor SNF at a geologic repository.

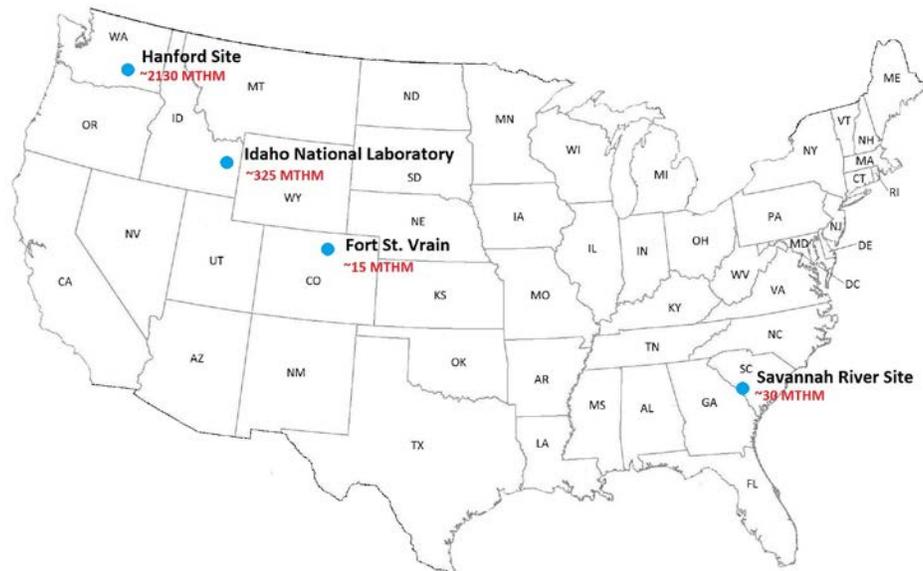


Figure 1. Major Storage Locations of DOE-Managed Spent Nuclear Fuel and Mass of Spent Nuclear Fuel Stored at Each Site in Metric Tons of Heavy Metal (MTHM). Mass Data from NWTRB (2016)

¹Metric ton of heavy metal is a commonly used measure of the mass of “heavy metal” in nuclear fuel. Heavy metal refers to elements with atomic number greater than 89 (*e.g.*, uranium, plutonium, and thorium). The mass of other constituents of the fuel, such as cladding, alloy materials, and structural materials, are not included. In the case of commercial nuclear fuel (see fact sheet on [Commercial SNF](#)), the unit of fuel mass often used is metric ton of uranium (MTU) because uranium is the only heavy metal present before irradiation in a reactor. A metric ton is 1,000 kg, which is equal to about 2,200 lb.

Approximately 27 MTHM of DOE-managed SNF currently remain stored in spent fuel pools at the Idaho National Laboratory and 30 MTHM in spent fuel pools at the Savannah River Site (NWTRB, 2016). The amount of DOE-managed SNF in dry storage will increase as DOE and the Navy transfer SNF at the Idaho National Laboratory from wet storage to dry storage. All the DOE-managed SNF will require packaging into MCOs or other standardized canisters prior to transport from the site where it is stored to storage elsewhere or disposal in a geologic repository.

COMPOSITION AND CHARACTERISTICS

DOE-managed SNF comes from a variety of reactor types and has a wide range of geometries, fuel matrices, cladding types, fissile materials, enrichments, and burnups² (SNL, 2014). The fissile materials in DOE-managed SNF include uranium-233, uranium-235, plutonium-239, neptunium-237, and americium-241 (Carter *et al.*, 2013). The uranium-235 enrichment or mass percent in DOE-managed SNF ranges from less than 0.71% to over 93%. Uranium that contains less than 0.71 mass percent uranium-235 is referred to as “depleted uranium” because the uranium-235 content is less than that of natural uranium. The burnup of DOE-managed SNF ranges from very slightly irradiated to over 500 GWd/MTU (SNL, 2014).

DOE-managed SNF comprises over 250 distinct fuel types and includes over 200,000 fuel pieces or assemblies of varying structures and sizes (NWTRB, 2016). The sizes and shapes of some of the DOE-managed SNF are illustrated in Figure 2. To facilitate analysis of the different SNF types, such as in evaluations of geologic repository performance, DOE categorized the DOE-managed SNF inventory into 34 fuel groups based on fuel matrix, cladding types, cladding condition, and enrichment (SNL, 2014). These are the fuel characteristics that DOE determined to have major impacts on the release of radionuclides from DOE-managed SNF and to affect evaluations of potential nuclear criticality. Table 1 shows the main characteristics of the DOE-managed SNF groups and lists their main sources and total mass.

A substantial amount of DOE-managed SNF is damaged. Some of the damage was caused by experimental activities and destructive examinations; incidents during packaging, handling, and transportation; or degradation during storage (Carlsen *et al.*, 2005). In some cases, the SNF was damaged on purpose to protect proprietary SNF designs. Examples of damage to the SNF include failed cladding, failed fuel material, sectioned test specimens, partially reprocessed SNF, and dismantled fuel assemblies

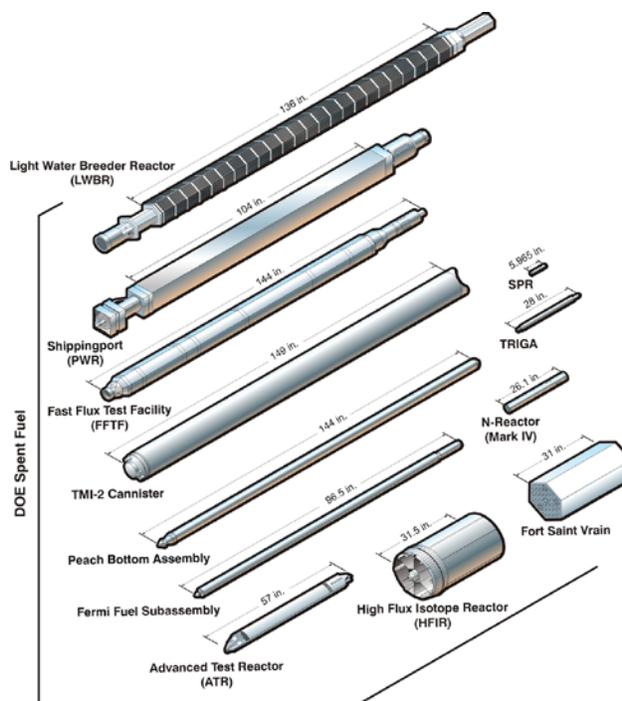


Figure 2. Examples of DOE-Managed SNF Fuel Types (INL, 2007)

²Burnup is the amount of energy extracted per unit mass of the fuel. Typical units for burnup are gigawatt-days per metric ton of heavy metal (GWd/MTHM) originally contained in the fuel or gigawatt-days per metric ton of uranium (GWd/MTU).

Table 1. Main Characteristics, Sources, and Mass of DOE-Managed Spent Nuclear Fuel Groups*

Group	Mass (MTHM)	% of Total Mass	Fuel Characteristics	Main source
1	2,100	84	Low-enriched uranium-metal SNF with zirconium cladding	Hanford Site N Reactor
13	108	4	Low-enriched uranium oxide SNF with failed non-aluminum cladding or with the cladding removed	About 75% by mass is core debris from Three Mile Island Unit-2 reactor accident
7	82	3	Low-enriched uranium oxide SNF with intact zirconium cladding	Commercial power reactors
31	56	2	SNF with sodium bonding between the fuel matrix and the cladding	Experimental fast-neutron breeder reactors
25	43	2	Thorium-oxide and uranium-oxide SNF with zirconium cladding	Shippingport Atomic Power Station with light water breeder reactor core
32	28	1	Naval SNF	Naval pressurized water reactors
19	25	1	Thorium carbide and uranium carbide SNF with tristructural isotropic- or buffered isotropic-coated particles embedded in a graphite matrix	Fort St. Vrain reactor
Other†	71	3	Variety of fuel types	Variety of sources

*Mass data as of January 2013 (NWTRB, 2016)
†“Other” includes the other 27 SNF groups that each contribute <1 % to the total mass of DOE-managed SNF.

(Carlsen *et al.*, 2005). A significant fraction of the Hanford N Reactor SNF (Group 1, the most abundant of the SNF groups listed in Table 1) has cladding that is visibly damaged and exposed uranium metal fuel surfaces that show extensive corrosion. The inventory of damaged SNF also includes the ~81.6 MTHM of nuclear reactor core debris from the Three Mile Island Unit 2 reactor.

MASS AND RADIOACTIVITY

As indicated above, there are approximately 2,500 MTHM of DOE-managed SNF as of January 2013 (NWTRB, 2016). For comparison, the U.S. inventory of commercial SNF was projected to be 75,790 MTHM by the end of 2015 (Carter and Vinson, 2015). The estimated radioactivity of the DOE-managed SNF inventory as of 2010 was 191 million curies (Carter *et al.*, 2013), which is less than 1% of the estimated radioactivity of the commercial SNF inventory, 23 billion curies in 2012 (Carter *et al.*, 2013). The total mass of DOE-managed SNF is projected to increase only slightly in the future as SNF is removed from naval nuclear propulsion units and, to a lesser extent, as SNF from domestic and foreign research and test reactors is returned to DOE for custody. By 2048, the year DOE set as its target for having a geologic repository for SNF and high-level radioactive waste constructed and operating (DOE, 2013), the total mass of DOE-managed SNF is projected to increase by approximately 37 MTHM, or less than 2% of the 2013 inventory (NWTRB, 2016). The total radioactivity of the DOE-managed SNF will decrease to about 160 million curies in 2048 due to radioactive decay.

STABILITY AND RADIONUCLIDE RELEASE IN A GEOLOGIC REPOSITORY

With dozens of different fuel groups, hundreds of different fuel types, and much of the fuel damaged, the dissolution processes and rates for the various types of DOE-managed SNF in a geologic repository likely will vary significantly. For most of the fuel types, there are no experimental data on the degradation and dissolution of the SNF in repository groundwater (BSC, 2004a). A DOE study (BSC, 2004a) previously

examined the available data on the dissolution kinetics of DOE-managed SNF to develop simplified models for assessing the performance of a geologic repository at Yucca Mountain, Nevada. The study recommended applying an “instantaneous” degradation model—the complete release of radionuclides upon exposure to groundwater—to DOE-managed SNF, except naval SNF, in repository performance assessments. The instantaneous degradation model was selected as a conservative estimate because the damaged and corroded Hanford N Reactor fuel, which constitutes the majority of the DOE-managed SNF (see Table 1), has a very high degradation rate and there are insufficient data to support a less conservative approach.

For naval SNF, the DOE study (BSC, 2004a) recommended applying the dissolution model developed for commercial SNF. The commercial SNF dissolution model takes account of the effects on dissolution rate of temperature, pH, and dissolved concentrations of oxygen and carbonate species (BSC, 2004b). It provides an upper bound on the degradation rate of naval SNF based on the results of a study conducted under the Naval Nuclear Propulsion Program that demonstrated the dissolution rate of naval SNF is lower than that of commercial SNF.

The DOE study (BSC, 2004a) did not evaluate the degradation of sodium-bonded SNF (Group 31 in Table 1) from the operation of experimental fast-neutron breeder reactors. Disposal of this type of fuel in a geologic repository would present a significant technical challenge because, depending on the state of degradation of the SNF canister and the fuel cladding, groundwater may come into contact with the sodium in the fuel elements and result in an energetic chemical reaction. The energetic chemical reaction may have a significant impact on the timing of radionuclide release from the SNF and, thus, on repository performance (SNL, 2014). DOE plans to treat all of the sodium-bonded fuel, except the blanket fuel from the Enrico Fermi Nuclear Power Plant (Fermi-1)³ that operated in Monroe, Michigan, using an electrometallurgical treatment and to dispose of the resulting metallic and ceramic waste forms as high-level radioactive waste (DOE, 2000). The Fermi-1 blanket fuel has different physical characteristics than the rest of the sodium-bonded fuel inventory. DOE will continue to store the Fermi-1 blanket fuel while alternative treatment options for this fuel are evaluated (DOE, 2000).

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³The Fermi-1 unit of the Enrico Fermi Nuclear Power Plant was a prototype fast breeder reactor that was officially decommissioned in 1975. The reactor core, which consisted of assemblies of uranium fuel enriched in uranium-235, was surrounded by a “blanket” of additional assemblies containing depleted uranium. The blanket fuel was used to create or “breed” plutonium-239, which is a fissile material.

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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.