CHAPTER 5

QUANTITIES, SOURCES, AND CHARACTERISTICS OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE IN THE UNITED STATES

5.1 INTRODUCTION

This chapter presents current and projected inventories of spent nuclear fuel and DOE defense high-level radioactive waste. Current plans call for both of these waste forms to be disposed of in the Yucca Mountain repository. The waste inventories cited are from sources of Federal Government information publicly available (DOE94a, DOE95a, DOE95b, DOE95c, DOE95d, DOE95e, DOE95f). The waste forms are inventoried by mass or volume and radioactivity content.

Since this BID was prepared, DOE has provided updated information on spent nuclear fuel in the Draft Environmental Impact Statement (DEIS)(DOE99). While some of the detailed waste inventory values reported in the DEIS may differ from those reported here, they do not substantively affect the technical discussion in this chapter nor EPA's regulatory considerations.

Information in this chapter describes fuel inventories either in terms of metric tons of initial heavy metal (MTIHM) or in terms of metric tons of heavy metal (MTHM) depending on the metric used in the source document. The former term (MTIHM) is useful since it is a metric that is independent of fuel burnup, while the latter term (MTHM) is useful since it is a metric that is consistent with the repository regulatory limit (i.e., 70,000 MTHM). Heavy metal refers to the mass of actinide elements (elements with atomic numbers greater than 89) in the fuel. Generally, the initial heavy metal is mostly uranium. Differences between MTIHM and MTHM are small.

5.2 SPENT NUCLEAR FUEL

Spent nuclear fuel is defined as fuel that has been withdrawn from a nuclear reactor following irradiation and whose constituent elements have not been separated by reprocessing (EPA85). Generators of spent nuclear fuel include: (1) commercial Light Water Reactors (LWR), which consist of Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR); (2) government-sponsored research and demonstration programs, DOE test and research reactors, universities, and industry; (3) experimental reactors, e.g., liquid-metal, fast-breeder reactors

(LMFBR) and high-temperature gas-cooled reactors (HTGR); (4) U.S. Government nuclear weapons production reactors; and (5) Department of Defense (DOD) reactors.

Approximately 98 percent of the spent nuclear fuel from commercial power reactors is stored at the reactor sites where it was generated; the rest is stored at central commercial storage facilities. The majority of DOE spent nuclear fuel is stored at three sites—the Hanford Site in Washington, the Idaho National Engineering and Environmental Laboratory (INEEL), and the Savannah River Site in South Carolina. Some of the Fort St. Vrain spent nuclear fuel is being stored at INEEL, but the remainder is being stored in Colorado at the Fort St. Vrain facility (DOE95a). The fuels at these DOE facilities are Government-owned and are not scheduled for reprocessing in support of DOE defense activities.

The fuel for LWRs consists of uranium dioxide pellets encased in zirconium alloy (Zircaloy) or stainless steel tubes. During reactor operation, fission of the uranium-235 produces energy, neutrons, and radioactive isotopes known as fission products. The neutrons produce further fission reactions and thus sustain the chain reaction. The neutrons also convert a portion of the uranium-238 into plutonium-239, which can also undergo fission. In time, the fissile uranium-235, which originally constituted some 3 to 4 percent of the enriched fuel, is depleted to such a level that power production becomes inefficient. Once this occurs, the fuel bundles are deemed "spent" and are removed from the reactor. In the United States, reprocessing of commercial spent nuclear fuel to recover the unfissioned uranium-235 and the plutonium for reuse as a fuel resource is currently not taking place, nor is it expected to occur in the future.

The radioactive materials associated with spent nuclear fuel fall into three categories: (1) fission products; (2) actinide elements (atomic numbers of 89 and greater); and (3) activation products. Typically, fresh spent nuclear fuel contains more than 100 radionuclides as fission products. Fission products are of particular importance because of the quantities produced, their high radiological decay rates, their decay-heat production, and their potential biological hazard. Such fission products include: strontium-90; technetium-99; iodine-129 and -131; cesium isotopes, such as cesium-134, -135, and -137; tin-126; and krypton-85 and other noble gases.

Activation products include tritium (hydrogen-3), carbon-14, cobalt-60, and other radioactive isotopes created by neutron activation of fuel assembly materials and impurities in cooling water or in the spent nuclear fuel. The actinides include uranium isotopes and transuranic elements, such as plutonium, curium, americium, and neptunium. The exact radionuclide composition of a

particular spent nuclear fuel sample depends on the reactor type, the initial fuel composition, the length of time the fuel was irradiated (also known as "burnup"), and the elapsed time since its removal from the reactor core.

5.2.1 Commercial Spent Nuclear Fuel Inventory and Projection

By the end of 1999, there were 40,000 MTIHM[15] of spent nuclear fuel in inventory from commercial reactor operations. Approximately 37,000 MTIHM is stored at reactor sites. The remainder is stored at the West Valley Demonstration Project (WVDP) (27 MTIHM) in West Valley, New York; the Idaho National Engineering and Environmental Laboratory (43 MTIHM) in Idaho Falls, Idaho; and the Midwest Fuel Recovery Plant (MFRP) (744 MTIHM) in Morris, Illinois (DOE95e). The historical (1970-1994) and projected (1995-2030) spent nuclear fuel inventories and accumulated radioactivities are given in Table 5-1.

Table 5-1. Historical and Projected Mass and Radioactivity of Commercial Spent Nuclear Fuel (DOE94a, DOE95e, DOE95f, DOE96a)

End of Calendar Year	Mass Accumulated (MTIHM)[a]	Radioactivity Accumulated (10^6 Ci)[b]
1970	55	215
1975	1,567	3,315
1980	6,558	10,137
1985	12,684	14,228
1990	21,547	22,910
1994	29,811	26,661
1995[c]	32,022	25,600
2000[c]	43,100	32,600
2005[c]	53,500	36,900
2010[c]	63,600	39,800
2015[c]	73,900	36,700
2020[c]	80,000	34,700
2025[c]	85,500	32,100
2030[c]	87,900	24,700

[a] Metric tons initial heavy metal refers to the original mass of the actinide elements of the fuel.
[b] A curie of radioactivity corresponds to 3.7×10^{10} disintegrations per second.
[c] Projections beyond 1994 are based on the DOE/EIA Low Case.

[15] Commercial spent nuclear fuel reported in DOE95e is in units of metric ton (tonne) of *initial* heavy metal (MTIHM) to avoid difficulties arising from the need to estimate ranges of varied heavy-metal content that result from different levels of enrichment and reactor fuel burnup. A metric ton is 1,000 kilograms, corresponding to about 2,200 pounds.

Projections of nuclear capacity are based on the DOE/EIA Low Case assumptions, which forecast an increase in the installed nuclear capacity from 99.1 gigawatts-electric (GW(e)) in 1994 to a peak of 100.3 GW(e) in 2000, then a decrease to 2.3 GW(e) by 2030, as shown in Table 5-2 (DOE95f). The Low Case scenario is based on these assumptions: (1) reprocessing of spent nuclear fuel will not occur; (2) currently licensed reactors will be retired when their initial license terms expire; and (3) new advanced LWRs will not be available before 2015. The DOE/EIA projections also assume that burnup levels of spent nuclear fuel will increase from their current average of 33,065 and 39,989 Megawatt days (MWd) per MTIHM to 42,000 and 54,000 MWd/MTIHM for BWRs and PWRs, respectively. This increase is predicted over the period 1994 to 2020. Based on currently-mandated limits, only 63,000 MTHM of commercial spent nuclear fuel can be accommodated at the Yucca Mountain site.

Table 5-2. Historical and Projected* Installed Nuclear Electric Power Capacity (DOE95f)

End of Calendar Year	Total GW(e)	End of Calendar Year	Total GW(e)
1960	0.3	1995*	99.1
1965	0.4	2000*	100.3
1970	5.8	2005*	100.3
1975	38.3	2010*	91.1
1980	51.9	2015*	61.4
1985	78.5	2020*	46.7
1990	99.6	2025*	22.0
1994	99.1	2030*	2.3

* Lower Reference Case projected capacity includes all existing reactors, completed or under construction, plus additional new reactors beyond the year 2005.

5.2.2 DOE Spent Nuclear Fuel

The DOE reprocessed most of its spent nuclear fuel in the facilities at INEEL, the Hanford Site, and the Savannah River Site. However, some spent nuclear fuel remains because of U.S. Government decisions to stop reprocessing. Most of this fuel came from the Hanford Site N-Reactor, a dual-purpose reactor designed to produce plutonium for use in nuclear weapons and to generate electricity for commercial use. Smaller amounts of spent nuclear fuel associated with nuclear weapons production are stored at the Savannah River Site. Spent nuclear fuel from the Naval Nuclear Propulsion Program is stored at INEEL and, for short time, at some naval nuclear shipyards. The DOE will also assume responsibility for fuel from some special-case commercial nuclear reactors, foreign research reactors, and certain domestic research and test reactors. The following sections discuss the nature and quantity of this spent nuclear fuel and DOE's plans to

manage it. Most of the discussion that follows is derived from the Spent Nuclear Fuel FEIS (DOE95c). Additional details are provided in the DEIS (DOE99).

Hanford Site

The Hanford Site produced plutonium for use in nuclear weapons from the start of the Manhattan Project until DOE halted production in 1989. Hanford's production reactors generated 2,100 MTHM of the existing DOE inventory of spent nuclear fuel. There is a total of 2,096 metric tons of spent N-reactor fuel at Hanford, which comprises all but about 1 percent by heavy metal mass of the spent nuclear fuel inventory at the site. This fuel is stored in three facilities; DOE's interim plans for management of this fuel include possible relocation to a single storage facility. Sources of the other spent nuclear fuel at the site included single-pass Hanford production reactors, the Fast Flux Test Facility, Shippingport Core H, and miscellaneous test facilities.

Idaho National Engineering and Environmental Laboratory

Six major facility areas at the INEEL store spent nuclear fuel: Argonne National Laboratory-West; Idaho Nuclear Technology and Engineering Center; Naval Reactors Facility; Power Burst Facility; Test Area North; and the Test Reactor Area. Spent nuclear fuel is kept in a variety of dry and wet configurations. The INEEL stores about 10 percent of DOE's current inventory of spent nuclear fuel, i.e., about 300 MTHM.

Savannah River Site

The DOE has 200 MTHM, or about 8 percent of its system-wide spent nuclear fuel inventory, in storage at the Savannah River Site. This fuel is stored in the Receiving Basin for Off-site Fuels (RBOF), in three reactor disassembly basins, and in basins in the F- and H-Area Canyons.

The F- and H-Area Canyons are among the only remaining operable chemical separation facilities of their kind in the DOE complex. Each canyon has an associated storage basin that serves as an interim staging area where spent nuclear fuel awaits chemical separation.

The DOE has stored most aluminum-clad spent nuclear fuel from Savannah River Site reactors in water-filled concrete basins. These basins contain spent nuclear fuel and target material. The

basin structures were built in the 1950s and were not intended for prolonged storage of radioactive materials.

The RBOF has been receiving fuels of U.S.-origin since 1964, including fuel manufactured in the United States but irradiated in foreign reactors. About 50 percent of the fuels in the SRS basins consist of uranium clad in stainless steel or zircaloy.

Other Generator/Storage Locations

The DOE has in its possession, or has title to, a small amount of spent nuclear fuel in many other locations throughout the United States. These locations include both DOE and non-DOE facilities. For example, the Oak Ridge National Laboratory (ORNL) stores less than 1 MTHM of spent nuclear fuel. This fuel is left over from research on fuel elements removed from commercial or demonstration reactors, as well as fuel removed from reactors that operated at ORNL. This fuel will be transferred to either INEEL or the Savannah River Site.

Besides ORNL, DOE is responsible for spent nuclear fuel from research and test reactors at the Brookhaven, Los Alamos, Sandia, and Argonne-East Laboratories. These facilities have a total of about two MTHM in storage. Other DOE sources include:

- Non-DOE Research Reactors - The DOE has title to the spent nuclear fuel that is stored at or is generated by 57 small research reactors. These reactors operate at universities, commercial establishments and other government agencies, such as the Department of Defense. These reactors have a current inventory of less than 5 MTHM and will generate very little additional spent nuclear fuel by 2035.

- Commercial Power Reactors - The DOE has possession of 125 spent nuclear fuel assemblies and 20 complete or sectioned spent nuclear fuel rods from several commercial power reactors that supported DOE-sponsored research and development programs. This fuel is stored at the West Valley Demonstration Project and at the Babcock and Wilcox Lynchburg Technology Center in Campbell County, Virginia. Other commercial spent nuclear fuel is already stored at the INEEL, the Hanford Site, and the Savannah River Site.

- Foreign Research Reactors - The DOE has accepted limited amounts of spent nuclear fuel from foreign reactors (WCM95a). In some cases, this fuel was manufactured by the DOE. The DOE will, under the Spent Nuclear Fuel FEIS, continue to receive and store spent nuclear fuel from foreign sources (DOE95c).

All the spent nuclear fuel listed above, if not already transferred, will be shipped to INEEL or the Savannah River Site, with the exception of Fort St. Vrain spent nuclear fuel, which will remain in Colorado.

Spent Nuclear Fuel Management Options

The Spent Nuclear Fuel FEIS says that most spent nuclear fuel in the possession of the DOE will be stored until a geologic repository is available. Most DOE spent nuclear fuel will be stored dry to reduce identified vulnerabilities. The DOE is also considering options to stabilize some of its corroding spent nuclear fuel (WCM95b). One of these options is "melt and dilute" at the Savannah River Site.

A summary inventory of DOE spent nuclear fuel is given in Table 5-3. Spent nuclear fuel in this listing includes material from fuels other than those discharged from production reactors.

Table 5-3 includes nuclear fuel that has been withdrawn from or resides in storage at a reactor following irradiation but that has not been reprocessed. Also included are some defective fuel elements and special nuclear forms, as well as some commercially generated nuclear fuels and fuels from foreign reactors and university research reactors.

The estimates in Table 5-3 have been recently updated by DOE (DOE98, vol. 3, Table 3-13). The more recent estimate is 2,496 MTHM. Based on legislative limits, only 2,333 MTHM is scheduled for disposal at Yucca Mountain.

5.3 DEFENSE HIGH-LEVEL RADIOACTIVE WASTE

High-level radioactive wastes are the highly radioactive materials resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste (EPA85, NWP83). Commercial high-level radioactive waste currently stored at the West Valley Demonstration Project will be converted to a solid form (glass) prior to disposal (NRC88). Substantial quantities of this waste have been vitrified.

Table 5-3. DOE Spent Nuclear Fuel Inventory (DOE95a)

Generator or Storage Site	Existing (1995)		Future Increases (through 2035)		Total (2035)	
	MTHM[a]	Percent	MTHM	Percent	MTHM	Percent
DOE Sites						
Hanford Site	2132.44	80.6	0.00	0.0	2132.44	77.8
Idaho National Engineering and Environmental Laboratory	261.23	9.9	12.92	13.5	274.14	10.0
Savannah River Site	206.27	7.8	0.00	0.0	206.27	7.5
Oak Ridge Reservation	0.65	<0.1	1.13	1.2	1.78	<0.1
Other DOE Sites	0.78	<0.1	1.50	1.6	2.28	<0.1
Naval Nuclear Propulsion Reactors	0.00[b]	0.0	55.00	57.6	55.00	2.0
Foreign Research Reactors	0.00	0.0	21.70	22.7	21.70	0.8
Non-DOE Domestic						
Domestic Research and Test Reactors[c]	2.22	<0.1	3.28	3.4	5.50	0.2
Special-Case Commercial SNF at non-DOE locations[d]	42.69	1.6	0	0	42.69	1.6
Total[e]	2646.27		95.53		2741.80	
Percent of 2035 total	96.5		3.5		100.0	

[a] MTHM = metric tons of heavy metal.
[b] The existing inventory of Naval Nuclear Propulsion Program spent nuclear fuel (10.23 MTHM) stored at the INEEL is included in the INEEL total.
[c] Includes research reactors at commercial, university, and government facilities.
[d] The total inventory of spent nuclear fuel from special case commercial reactors is 186.41 MTHM. The 42.69 MTHM listed here is that stored at the Babcock & Wilcox Research Center, Fort St. Vrain Reactor, and West Valley Demonstration Project. The remaining special-case commercial spent nuclear fuel is stored at the INEEL, the Oak Ridge Reservation, and the Savannah River Site, and is included in the totals for those locations.
[e] Numbers may not sum due to rounding.

High-level waste is generated by the chemical reprocessing of spent research and production reactor fuel, irradiated targets, and naval propulsion fuel. The fission products, actinides, and neutron-activated products of particular importance are the same for high-level waste as they are for spent nuclear fuel assemblies (DOE88, DOE95e).

Weapons program reactors were operated mainly to produce plutonium. Reprocessing to recover the plutonium was an integral part of the weapons program. Naval propulsion and DOE research/test reactor fuel elements were also reprocessed to recover the highly enriched uranium that remained after use. DOE decided in 1992 to phase out the domestic reprocessing of irradiated nuclear fuel of defense program origin, so minimal amounts of high-level waste will be added to the current inventory.

High-level radioactive waste that is generated by the reprocessing of spent reactor fuel and targets contains more than 99 percent of the nonvolatile fission products produced in the fuel or targets during reactor operation. It generally contains about 0.5 percent of the uranium and plutonium originally present in the fuel. Most of the current high-level waste inventory, which is the result of DOE national defense activities, is stored at the Savannah River Site, INEEL, and the Hanford Site. A limited quantity of high-level waste is stored at the West Valley Demonstration Project. These high-level wastes have to date been through one or more treatment steps (e.g., neutralization, precipitation, decantation, evaporation). It is currently planned that this HLW will be solidified, using a vitrification process, for disposal. Vitrification is well underway at the Savannah River Site and the West Valley Demonstration Project.

The DOE defense high-level waste at INEEL results from reprocessing nuclear fuels from naval propulsion reactors and special research and test reactors. The bulk of this waste, which is acidic, has been converted to a stable, granular solid (calcine). At the Savannah River and Hanford Sites, the acidic liquid waste from reprocessing defense reactor fuel is or has been made alkaline by the addition of caustic soda and stored in tanks. During storage, this alkaline waste separates into three phases: liquid, sludge, and salt cake. The relative proportions of liquid and salt cake depend on how much water is removed by waste treatment evaporators during waste management operations.

Both alkaline and acidic high-level wastes were generated at West Valley. The alkaline waste was generated by reprocessing commercial power reactor fuels and some Hanford N-Reactor fuels. Acidic waste was generated by reprocessing a small amount of commercial fuel containing thorium.

Projected volumes and total radioactivity for high-level waste stored at the Hanford Site, INEEL, the Savannah River Site, and WVDP are given in Table 5-4. Projected inventories for each site are based on specific assumptions and are subject to change. New treatment methods and waste forms are possible and may affect the future projections. Since all sites are progressing toward closure, there should be minimal amounts of waste added to the current inventory. Interim storage of DOE high-level waste will be required and will most likely be at the site where the waste is produced.

DOE currently estimates that 10,110 MTHM of HLW will be available for disposal (DOE98, Vol. 3, Section 3.5.1.5). Of this total, only 4,667 MTHM are actually scheduled for disposal based on a regulatory limit for the repository of 70,000 MTHM of spent nuclear fuel and HLW.

Table 5-4. Historical and Projected Cumulative Volume and Radioactivity of High-Level Waste Stored in Tanks, Bins, and Capsules By Site (DOE95d, DOE95e)

End of Calendar Year	Volume, 10^3 m^3					Radioactivity, 10^6 Ci				
	Hanford	INEEL	SRS	WVDP	Total	Hanford	INEEL	SRS	WVDP	Total
1980	219.4	11.4	96.7	2.2	329.7	576.7	53.4	699.0	33.5	1,362.6
1981	219.4	12.0	105.7	2.2	339.3	550.2	63.6	982.0	32.7	1,628.5
1982	213.3	11.5	115.0	2.2	342.0	437.1	71.6	828.8	31.9	1,369.4
1983	229.4	9.7	111.4	2.2	352.7	427.5	64.8	776.2	31.2	1,299.7
1984	225.6	10.1	125.6	2.2	363.5	470.2	58.6	795.9	30.5	1,355.2
1985	222.1	10.1	122.7	2.2	357.1	519.0	69.4	841.4	29.7	1,459.5
1986	226.4	9.5	127.8	2.2	365.9	534.6	60.6	794.7	29.1	1,419.0
1987	239.7	11.9	127.6	2.2	381.4	478.2	62.5	734.0	28.4	1,303.1
1988	243.4	11.0	128.4	2.1	384.9	447.4	67.0	664.4	27.9	1,206.7
1989	244.8	12.0	122.0	2.4	381.1	419.3	68.4	598.9	27.3	1,113.9
1990	253.6	12.0	131.7	1.2	398.5	399.3	63.2	561.6	26.7	1,050.8
1991	256.4	10.4	127.9	1.7	396.5	384.2	59.4	537.6	26.2	1,007.4
1992	258.7	11.2	126.9	1.6	398.3	372.1	50.8	632.4	25.9	1,081.2
1993	261.7	10.5	129.3	2.0	403.5	361.4	52.5	606.0	25.3	1,045.3
1994	238.9	11.0	126.3	2.2	378.4	348.0	51.6	534.5	24.7	958.8
1995	237.3	11.4	122.1	0.9	371.7	339.9	50.5	502.2	24.1	916.7
2000	232.1	9.8	98.7	0	340.6	302.4	44.1	352.7	0	699.2
2005	229.6	9.5	75.2	0	314.2	269.1	38.9	239.5	0	547.5
2010	197.9	9.8	51.7	0	259.4	232.2	34.6	147.0	0	413.8
2015	134.4	10.4	28.2	0	173.0	128.9	30.8	71.7	0	231.3
2020	70.8	7.2	4.7	0	82.8	45.5	26.9	10.7	0	83.1
2025	26.3	5.8	0	0	32.0	15.2	13.8	0	0	29.0
2030	2.4	4.1	0	0	6.5	0	3.9	0	0	3.9

5.3.1 High-Level Waste Inventories at the Hanford Site

The alkaline high-level waste (239,000 m^3) located at Hanford is stored in underground carbon-steel tanks. Currently 155,800 m^3 is solid (salt cake and sludge) and 83,200 m^3 is liquid; waste volumes change with time because of on-going waste management activities. There are approximately 350 million curies of total radioactivity contained in the waste, which has been accumulating since 1944. The high-level waste was generated by reprocessing production reactor fuel for the recovery of plutonium, uranium, and neptunium for defense and other Federal programs.

All of the fuel reprocessing methods generated acidic waste streams. Sodium hydroxide or calcium carbonate was added to the waste before it was transferred to the tanks to neutralize the acid and minimize tank corrosion. The tanks currently contain moderate to strong alkaline solutions. Additional post-processing of the waste to recover plutonium and uranium, or to reduce the volume of high-level waste, has resulted in the addition of ferrocyanide and some organic compounds listed as hazardous. Fuel reprocessing was suspended from 1972 until November 1983. Most of the high-heat-emitting isotopes (strontium-90, cesium-137, and their decay products) have been removed from the old waste, converted to solids as strontium fluoride and cesium chloride, placed in double-walled capsules, and stored in water basins. A total of 2,217 capsules were manufactured and 1,933 remain. (A portion of these capsules have been used outside the facility or have been dismantled.)

Double-shell tanks continue to receive waste generated by decommissioning and cleanup of Hanford Site facilities. This includes: effluents associated with the deactivation program for the PUREX Plant; waste from B-Plant maintenance activities; laboratory waste; and miscellaneous waste streams from ion-exchanger resin regeneration.

The tanks now contain a mixture of salt cake, liquid, and sludges with both radioactive and hazardous components. Sludge consists primarily of solids (hydrous metal oxides) precipitated from the neutralization of acid waste. Salt cake consists of the various salts formed from the evaporation of water from the waste. Liquids exist as supernatant (liquid above solids) and interstitial liquid (liquid filling the void between solids) in the tanks.

The tank waste is mostly inorganic, containing sodium hydroxide; salts of nitrate, nitrite, carbonate, aluminate, and phosphate; and hydrous oxides of aluminum, iron, and manganese.

The radioactive components consist primarily of long-lived fission products and shorter-lived radionuclides, such as strontium-90 and cesium-137, and isotopes of uranium, plutonium, and americium. Some tanks contain the chelating agents EDTA and HEDTA. Some contain halogenated and nonhalogenated organic contamination, while others contain mixed waste with detectable levels of lead, chromium, and cadmium.

DOE has in place a program to treat and remediate some of this tank waste. In August 1998 DOE awarded a contract to BNFL Inc. to undertake tank waste remediation. Under the contract BNFL will spent the initial two years in facility design. Assuming that DOE provides approval, a facility will then be constructed and remediation will begin. Facility operation is expected to begin in 2005 or 2006 and, during the initial ten-year operational period, DOE expects to process waste from 11 storage tanks. The material treated during this initial phase is estimated to constitute about 10 percent of the total waste mass and 20 to 25 percent of the total radioactivity. DOE plans to separate tank contents into high-level and low-level components, thereby reducing the amount of high-level radioactive waste. All remaining high-level liquid waste would then be vitrified and placed in stainless steel canisters for storage on site until a geologic repository is available for disposal. Vitrification is also planned for the low-level (low activity) waste. A privatized high-level waste vitrification plant is currently scheduled to begin operation on HLW in 2007 (90 percent confidence date) (DOE98a).

5.3.2 High-Level Waste Inventories at INEEL

About 11,000 m^3 of high-level waste, containing approximately 50 million curies of total radioactivity, is currently stored at INEEL; this volume consists of 7,200 m^3 of acidic liquid waste (1,306 m^3 is high-level waste; the remainder is high-level waste that contains sodium) and 3,800 m^3 of solid materials. Liquid high-level waste was generated at INEEL primarily by the reprocessing of spent nuclear fuel from the national defense (naval propulsion nuclear reactors) and reactor testing programs; a small amount was also generated by reprocessing fuel from non-defense research reactors. This acidic waste is stored underground in large, high-integrity, stainless steel tanks and these tanks are inside concrete vaults. Waste that has been converted to a calcine is stored in retrievable stainless steel bins housed in reinforced concrete vaults. Greater than 90 percent of the total radioactivity is contained in the calcine.

5.3.3 High-Level Waste Inventories at the Savannah River Site

Approximately 126,300 m^3 of alkaline high-level waste that has accumulated at the Savannah River Site over the past three decades is currently stored underground in carbon-steel tanks. The current inventories consist of alkaline liquid, sludge, and salt cake that were generated primarily by the reprocessing of nuclear fuels and targets from plutonium production reactors. The sludge is formed after treatment with caustic agents. Salt cake results when the supernatant liquor is concentrated in waste treatment evaporators. The high-level waste consists of 58,100 m^3 of liquid and 68,200 m^3 of solid material having a total radioactivity of approximately 500 million curies.

Tank farms at the Savannah River Site contain 24 single-shell and 27 double-shell tanks for storing high-level waste. The DOE plans to remove the liquid waste from these tanks by 2035 (DOE95d). The removal process includes these process steps involved in vitrifying the waste:

- The salt solution is removed from the tanks and treated in the salt processing facility.
- At the Defense Waste Processing Facility, which began operation in 1996, the sludge is combined with glass frit and vitrified. The vitrified waste is contained in stainless steel canisters.

5.3.4 High-Level Waste Inventories at the West Valley Demonstration Project

About 2,180 m^3 of high-level waste is stored at the WVDP facility and consists of 2,040 m^3 of liquid alkaline waste and 140 m^3 of solid waste (consisting of alkaline sludge and inorganic zeolite ion-exchange medium). The alkaline waste is stored in an underground carbon-steel tank, and the zeolite waste is stored in an underground carbon-steel tank covered by an aqueous alkaline solution. Reprocessing was discontinued at the WVDP in 1972. No additional high-level waste has been generated since.

In June 1996, the vitrification of HLW into glass logs was initiated at the WVDP. The glass logs are two feet in diameter by 10 feet long. As of mid-1999, more than 680 glass logs have been made.

5.4 SIGNIFICANT RADIONUCLIDES CONTAINED IN SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

Of the 70,000-tonne capacity limit for Yucca Mountain, about 40,785 MTHM and 22,210 MTHM represent spent PWR and spent BWR fuel, respectively (DOE95g). About 4,667 MTHM of vitrified high-level waste and 2,333 MTHM of DOE spent nuclear fuel represent the balance of the total repository inventory. For the Yucca Mountain Site, radionuclide-specific activity levels are estimated by assuming that all spent fuel had been removed from the reactors 30 years before emplacement with burnups of 39,651 MWd/MTHM for PWR fuel and 31,186 MWd/MTHM for BWR fuel[16]. Although the burnup of spent fuel producing HLW is generally unknown, this uncertainty is thought to affect the adjustment for decay only marginally.

Table 5-5 lists some radionuclide inventories for PWR and BWR reactor fuels, based on the DOE assumptions concerning burnup and cooling time as cited above. These values are generated from the ORIGEN2 computer code (ROD86), which calculates depletion, buildup, and decay of isotopes for given fuel initial conditions and utilization histories. Also shown in Table 5-5 are estimated nuclide inventories for the defense high-level waste, based on assumptions comparing burnup and fissile material contents for fuel from defense production reactors and commercial power reactors. The values shown in Table 5-5 demonstrate that the radionuclide inventories in a repository at Yucca Mountain stemming from defense high-level wastes are expected to be much less than those from commercial spent fuel.

The radionuclide inventory of the repository will change with time due to radioactive decay and ingrowth of radioactive decay products. For example, inventories of the initially-prominent fission products Cs-137 and Sr-90, which have approximately 30-year half lives, will decay to insignificant levels within 1,000 years, while some decay products, such as Pb-210 and Ra-226, will not achieve peak values until about 100,000 years after repository closure. Activity levels for very long-lived radioisotopes will maintain low but nearly constant levels for periods on the order of a million years. Overall, the radioisotope inventory of the wastes placed in the repository will decrease by about five orders of magnitude during the first 100,000 years after closure, and remain virtually constant thereafter.

[16] Inventory and burnup values were slightly revised in the 1998 Viability Assessment.

Table 5-5. Radionuclide Inventories in Spent Nuclear Fuel and High-Level Wastes Expected to be Disposed in a Yucca Mountain Repository*

Isotope	BWR Inventory	PWR Inventory	HLW Inventory	Combined Weighted Average
Ac-227	1.70×10^{-5}	1.85×10^{-5}	6.17×10^{-4}	7.79×10^{-5}
Ag-108m	9.82×10^{-3}	1.14×10^{-2}	0	9.76×10^{-3}
Am-241	2.50×10^{3}	3.67×10^{3}	1.05×10^{3}	3.04×10^{3}
Am-242m	8.38×10^{0}	1.03×10^{1}	1.70×10^{-1}	8.68×10^{0}
Am-243	1.00×10^{1}	2.09×10^{1}	2.36×10^{-1}	1.54×10^{1}
C-14	1.43×10^{0}	1.46×10^{0}	0	1.30×10^{0}
Cl-36	1.04×10^{-2}	1.14×10^{-2}	0	9.94×10^{-3}
Cm-243	7.21×10^{0}	1.61×10^{1}	4.29×10^{-2}	1.17×10^{1}
Cm-244	3.52×10^{2}	9.86×10^{2}	2.77×10^{1}	6.89×10^{2}
Cm-245	6.24×10^{-2}	2.20×10^{-1}	5.47×10^{-4}	1.48×10^{-1}
Cm-246	1.08×10^{-2}	4.39×10^{-2}	6.19×10^{-5}	2.90×10^{-2}
Cs-135	4.32×10^{-1}	5.04×10^{-1}	2.98×10^{-1}	4.61×10^{-1}
Cs-137	5.19×10^{4}	6.96×10^{4}	2.97×10^{4}	6.00×10^{4}
I-129	2.75×10^{-2}	3.74×10^{-2}	3.44×10^{-6}	3.05×10^{-2}
Mo-93	5.56×10^{-4}	2.76×10^{-2}	0	1.62×10^{-2}
Nb-94	2.95×10^{-2}	1.41×10^{0}	6.93×10^{-5}	8.30×10^{-1}
Ni-59	1.01×10^{0}	4.21×10^{0}	1.12×10^{-1}	2.78×10^{0}
Ni-63	1.23×10^{2}	5.44×10^{2}	8.13×10^{0}	3.57×10^{2}
Np-237	2.87×10^{-1}	4.27×10^{-1}	6.69×10^{-2}	3.46×10^{-1}
Pa-231	3.53×10^{-5}	3.82×10^{-5}	1.44×10^{-2}	1.47×10^{-3}
Pb-210	5.34×10^{-7}	5.37×10^{-7}	0	4.82×10^{-7}
Pd-107	8.70×10^{-2}	1.28×10^{-1}	2.74×10^{-2}	1.05×10^{-1}
Pu-238	1.61×10^{3}	2.87×10^{3}	9.27×10^{2}	2.28×10^{3}
Pu-239	2.97×10^{2}	3.53×10^{2}	1.13×10^{1}	3.01×10^{2}
Pu-240	4.64×10^{2}	5.34×10^{2}	7.77×10^{0}	4.59×10^{2}
Pu-241	3.09×10^{4}	4.61×10^{4}	3.49×10^{2}	3.67×10^{4}
Pu-242	1.18×10^{0}	2.05×10^{0}	1.16×10^{-2}	1.57×10^{0}
Ra-226	2.19×10^{-6}	2.24×10^{-6}	0	2.00×10^{-6}
Se-79	3.73×10^{-1}	4.96×10^{-1}	1.88×10^{-1}	4.26×10^{-1}
Sm-151	2.80×10^{2}	3.66×10^{2}	4.66×10^{2}	3.49×10^{2}
Sn-121m	9.52×10^{-1}	6.08×10^{-1}	5.91×10^{-2}	6.62×10^{-1}
Sn-126	6.26×10^{-1}	9.01×10^{-1}	5.10×10^{-1}	7.75×10^{-1}
Sr-90	3.79×10^{4}	4.91×10^{4}	2.93×10^{4}	4.36×10^{4}
Tc-99	1.22×10^{1}	1.55×10^{1}	6.33×10^{0}	1.35×10^{1}
Th-229	2.07×10^{-7}	3.66×10^{-7}	2.04×10^{-4}	2.07×10^{-5}
Th-230	3.53×10^{-4}	3.72×10^{-4}	2.90×10^{-4}	3.58×10^{-4}
U-232	1.79×10^{-2}	4.16×10^{-2}	2.12×10^{-2}	3.20×10^{-2}
U-233	4.30×10^{-5}	6.57×10^{-5}	2.41×10^{-2}	2.46×10^{-3}
U-234	1.41×10^{0}	1.56×10^{0}	3.40×10^{-2}	1.36×10^{0}
U-235	2.25×10^{-2}	2.30×10^{-2}	2.22×10^{-4}	2.06×10^{-2}
U-236	2.66×10^{-1}	3.37×10^{-1}	1.11×10^{-3}	2.81×10^{-1}
U-238	3.18×10^{-1}	3.13×10^{-1}	8.98×10^{-3}	2.84×10^{-1}
Zr-93	1.98×10^{0}	2.36×10^{0}	1.55×10^{0}	2.16×10^{0}

*Inventories for spent BWR and PWR fuel are in curies per initial metric ton of heavy metal. Inventories for HLW are for estimated equivalent metric tonnes of heavy metal. Values are based on burnup and cooling histories assumed by DOE.

REFERENCES

DOE88 U.S. Department of Energy, *Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area*, DOE/RW-0199, December 1988.

DOE94a U.S. Department of Energy, Energy Information Administration, *Nuclear Fuel Data Form RW-859*, December 1994.

DOE95a U.S. Department of Energy, *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement*, DOE/EIS-0203-F, April 1995.

DOE95b U.S. Department of Energy, Office of Scientific and Technical Information, *Nuclear Reactors Built, Being Built, or Planned: 1994*, DOE/OSTI-8200-R58, August 1995.

DOE95c U.S. Department of Energy, *Draft Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*, DOE/EIS-0200-D, August 1995.

DOE95d U.S. Department of Energy, *Integrated Data Base Report-1994: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics, Revision 10*, September 1995.

DOE95e U.S. Department of Energy, *Integrated Data Base Report-1994: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics, Revision 11*, September 1995.

DOE95f U.S. Department of Energy, Energy Information Administration, *World Nuclear Outlook 1995*, DOE/EIA-0436(95), October 1995.

DOE95g U.S. Department of Energy, *Total System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository*, TRW Environmental Safety Systems, Inc., B0000000-01717-2200-00136, Revision 01, November 1995.

DOE96a U.S. Department of Energy, *Integrated Data Base Report - 1995*, Revision 12, December 1996.

DOE98 U.S. Department of Energy, *Viability Assessment of a Repository at Yucca Mountain*, DOE/RW-0508, December 1998.

DOE99 U.S. Department of Energy, *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain,* DOE/EIS-02050D, Appendix A, July 1999.

DOE98a U.S. Department of Energy, *Report to Congress: Treatment and Immobilization of Hanford Radioactive Waste*, available on Hanford website at www.hanford.org.

EPA85 U.S. Environmental Protection Agency, *Draft Environmental Impact Statement for 40 CFR Part 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, EPA 520/1-85-023, August 1985.

NRC88 U.S. Nuclear Regulatory Commission, Code of Federal Regulations, Title 10, Part 60, *Disposal of High-Level Radioactive Wastes in Geologic Repositories*, as amended, October 1988.

NWP83 *Nuclear Waste Policy Act of 1982*, Public Law 97-425, January 7, 1983.

ROD86 Roddy, J.W., H.C. Claiborne, R.C. Ashline, P.J. Johnson, and B.T. Rhyne, *Physical and Decay Characteristics of Commercial LWR Spent Fuel*, ORNL/TM-9591/V2&R1, Oak Ridge National Laboratory, Oak Ridge, TN, 1986.

WCM95a *Spent Fuel Goes to Idaho Following State-DOE-Navy Agreement*, Weapons Complex Monitor, October 26, 1995.

WCM95b *OE Chooses Reprocessing for Selected Spent Fuel*, Weapons Complex Monitor, December 13, 1995.