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Radioactive Waste Streams: An Overview of Waste Classification for Disposal

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Summary

Radioactive waste is a byproduct of nuclear weapons production, commercial nuclear power generation, and the naval reactor program. Waste byproducts also result from radioisotopes used for scientific, medical, and industrial purposes. The legislative definitions adopted for radioactive wastes, for the most part, refer to the processes that generated the wastes. Thus, waste disposal policies have tended to link the processes to uniquely tailored disposal solutions. Consequently, the origin of the waste, rather than its radiologic characteristics, often determines its fate.

Plutonium and enriched uranium-235 were first produced by the Manhattan Project during World War II. These materials were later defined by the Atomic Energy Act of 1954 as *special nuclear materials*, along with other materials that the former Atomic Energy Commission (AEC) determined were capable of releasing energy through nuclear fission. Reprocessing of irradiated nuclear fuel to extract special nuclear material generated highly radioactive liquid and solid byproducts. The Nuclear Waste Policy Act of 1982 (NWPA) defined irradiated fuel as *spent nuclear fuel,* and the byproducts as *high-level waste*. Uranium ore processing technologically enhanced naturally occurring radioactive material and left behind uranium mill tailings. The fabrication of nuclear weapons generated *transuranic waste*. Both commercial and naval reactors continue to generate spent fuel. High-level waste generation has ceased in the United States, as irradiated fuel is no longer reprocessed. The routine operation and maintenance of nuclear reactors, however, continues to generate *low-level radioactive waste*, as do medical procedures using radioactive isotopes.

The NWPA provides for the permanent disposal of spent nuclear fuel and high-level radioactive waste in a deep geologic repository. The repository is to be constructed and operated by the Department of Energy (DOE) under the Nuclear Regulatory Commission's (NRC) licensing authority. Yucca Mountain, in Nevada, is the candidate site for the nation's first repository.

The NRC and the Environmental Protection Agency (EPA) share regulatory authority for radioactive waste disposal. However, these regulatory agencies have yet to adopt uniform radiation protection standards for disposal sites. The NRC's jurisdiction, however, does not extend to DOE's management of defense-related waste at DOE facilities other than Yucca Mountain.

Radioactive waste classification continues to raise issues for policymakers. Most recently, DOE policy on managing the residue in high-level waste storage tanks proved controversial enough that Congress amended the definition of high-level waste. The disposition of waste with characteristics left undefined by statute can be decided by an NRC administrative ruling. The case for *low-activity waste* promises to provoke similar controversy. This report will be updated as new radioactive waste classification issues arise.

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Background

Radioactive waste is a byproduct of nuclear weapons production, commercial nuclear power generation, and the naval reactor program. Waste byproducts also result from radioisotopes used for scientific, medical, and industrial purposes. Waste classification policies have tended to link the processes that generate the waste to uniquely tailored disposal solutions. Consequently, the origin of the waste, rather than its radiologic characteristics, often determines its fate.

Congress recently renewed its interest in radioactive waste classification when a Department of Energy (DOE) order regarding the disposition of high-level waste storage tank residue was legally challenged. As a result, Congress amended the statutory definition of high-level waste to exclude such residue.[1] The classification of other radioactive wastes continues to remain an aspect of disposal policy.

The Atomic Energy Act of 1946 (P.L. 79-585) defined *fissionable materials* to include plutonium, uranium-235, and other materials that the Atomic Energy Commission (AEC) determined to be capable of releasing substantial quantities of energy through nuclear fission. *Source material* included any uranium, thorium, or beryllium containing ore essential to producing fissionable material, and *byproduct material* remaining after the fissionable material's production. In the amended Atomic Energy Act of 1954 (P.L. 83-703), the term *special nuclear material* superseded fissionable material and included uranium enriched in isotope 233, material the AEC determined to be special nuclear material, or any artificially enriched material.[2]

As the exclusive producer, the AEC originally retained title to all fissionable material for national security reasons. In the 1954 amended act, Congress authorized the AEC to license commercial reactors, and ease restrictions on private companies using special nuclear material. Section 183 (Terms of Licenses) of the act, however, kept government title to all special nuclear material utilized or produced by the licensed facilities in the United States. In 1964, the AEC was authorized to issue commercial licenses to possess special nuclear material subject to specific licensing conditions (P.L. 88-489).

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[1] Section 3116 (Defense Site Acceleration Completion), Ronald W. Reagan Defense Authorization Act of FY2005 (P.L. 108-375).

[2] Laws of 83rd Congress, 2nd Session, 1118-21.

Although the Atomic Energy Act referred to *transuranic waste* (material contaminated with elements in atomic number greater than uranium), radioactive waste was not defined by statute until the 1980s. *High-level waste* and *spent nuclear fuel* were defined by the Nuclear Waste Policy Act (NWPA) of 1982 (42 U.S.C. 10101). Spent nuclear fuel is the highly radioactive fuel rods withdrawn from nuclear reactors. High-level waste refers to the byproduct of reprocessing irradiated fuel to remove plutonium and uranium. *Low-level radioactive waste* was defined by the Low-Level Radioactive Waste Policy Act of 1980 (P.L. 95-573) as radioactive material that is not high-level radioactive waste, spent nuclear fuel, or byproduct material, and radioactive material that the Nuclear Regulatory Commission (NRC) classifies as low-level radioactive waste consistent with existing law.

Measurement of Radioactivity and Hazards of Radiation

The measurement of radioactivity and the hazards of radiation are, in themselves, complex subjects. A discussion of radioactive waste would be incomplete without reference to some basic terms and concepts.

Radioactive elements decay over time. The process of radioactive decay transforms an atom to more a stable element through the release of radiation — *alpha* particles (two protons and two neutrons), charged *beta* particles (positive or negative electrons), or *gamma* rays (electromagnetic radiation).

Radioactivity is expressed in units of *curies* — the equivalent of 37 billion (37×10^9) atoms disintegrating per second. The rate of radioactive decay is expressed as *half-life* — the time it takes for half the atoms in a given amount of radioactive material to disintegrate. Radioactive elements with shorter half-lives therefore decay more quickly.

The term for the absorption of radiation by living organisms is *dose*. The United States uses the *Roentgen Equivalent Man* (rem) as the unit of equivalent dose in humans. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation.[3] Not all radiation has the same biological effect, even for the same amount of absorbed dose, as some forms of radiation are more efficient than others in transferring their energy to living cells.

In 1977, the International Commission on Radiation Protection (ICRP) concluded that an individual's mortality risk factor from radiation-induced cancers was about 1×10^{-4} from an exposure of one rem dose (one lifetime chance out of 10,000 for developing fatal cancer per rem), and recommended that members of the

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[3] Rem is the product of the dose measured in units of rad (100 ergs/gram) multiplied by a quality factor (Q) for each type of radiation; that is rem = rad x Q. For gamma rays, Q = 1, thus the absorbed dose in rads equals rems. For neutrons Q = 5, and alpha particles Q = 20; thus an absorbed dose of 1 rad is equivalent to 5 rem and 20 rem respectively.

public should not receive annual exposures exceeding 500 millirem.[4] The exposure limit is made up of all sources of ionizing radiation that an individual might be exposed to annually, which includes natural background and artificial radiation. An individual in the United States receives an average annual effective dose equivalent to 360 millirem, as shown in **Table 1**.

Table 1. Contribution to Average Annual Exposures from Natural and Artificial Radioactive Sources

Contributor	millirem
Natural - Radon	200
Natural background radiation	100
Occupational related exposure	0.9
Consumer products excluding tobacco	13
Miscellaneous environmental sources	0.06
Medical - diagnostic x rays	39
Medical - nuclear medicine	14
Average Annual Effective	360

Source: National Council on Radiation Protection and Measurements, Report No. 9, *Ionizing Radiation Exposure of the Population of the United States*, September 1, 1987.

The ICRP revised its conclusion on risk factors in 1990, and recommended that the annual limit for effective dose be reduced to 100 millirem.[5] This limit is equivalent to natural background radiation exclusive of radon. ICRP qualified the recommendation with data showing that even at a continued exposure of 500 millirem, the change in age-specific mortality rate is very small — less than 4.5% for females, less than 2.5% for males older than 50 years, and even less for males under age 50.

The radiation protection standards for NRC activities licensed under 10 C.F.R. Part 20[6] are based on a radiation dose limit of 100 millirem, excluding contributions from background radiation and medical procedures. Unlike the NRC's dose-based approach to acceptable hazard level, the Environmental Protection Agency (EPA) uses a risk-based approach that relies on the "linear, no-threshold" model of low-level radiation effects. In the EPA model, risk is extrapolated as a straight line from the high-dose exposure for Hiroshima and Nagasaki atomic bomb survivors down to zero radiation exposure. Thus, the EPA model attributes risk to natural background levels of radiation. For illustrative purposes, EPA considers a 1-in-10,000 risk that

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[4] Recommendations of the International Commission on Radiological Protection, January 1977 (superseded by ICRP 60) (supersedes ICRP 1, 6 & 9).

[5] International Commission on Radiation Protection, *Recommendation of the International Commission on Radiation Protection* — Publication 60, Paragraph 161, 1990.

[6] Part 20 — Standards for Protection Against Radiation.

an individual will develop cancer to be excessive, and has set a goal of 1-in-a-million risk in cleanup of chemically contaminated sites. The Government Accountability Office (GAO) has concluded that the low-level radiation protection standards administered by EPA and NRC do not have a conclusive scientific basis, as evidence of the effects of low-level radiation is lacking.[7]

Comparative Range of Radioactivity

The comparative range in radioactivity of various wastes and materials is presented in **Figure 1**. Radioactivity is typically expressed in terms of "curies/gram" for soil-like materials as well as radioactive materials that are homogeneous in nature. However, because the inventories of some radioactive wastes are tracked in terms of "curies/cubic- meter," that unit of measure has been used here.

The lowest end of the scale (at the bottom of the figure) is represented by soils of the United States — the source of natural background radiation. Radioactivity ranging from 3 to 40 microcuries/cubic-meter may be attributed to potassium, thorium and uranium in soils. Phosphogypsum mining waste is the byproduct of ore processing that "technologically enhanced naturally occurring radioactive material" (uranium) at higher levels than natural background (thus the term — TENORM), and may range from 6.5 to 45 microcuries/cubic-meter. Uranium mill tailings (referred to as 11e.(2) byproduct material) range from 97 to 750 microcuries/cubic-meter at various sites (**Appendix, Table A-1**). On average, low-level waste ranges from 6.7 to 20 curies/cubic-meter based on the inventory of disposal facilities (**Appendix, Table A-2**); a lower limit is left undefined by regulation, but an upper limit is set at 7,000 curies/cubic-meter based on specific constituents. Transuranic waste ranges between from 47 to 147 curies/cubic-meter based on the Waste Isolation Pilot Plant inventory. The vitrified high-level waste processed by the Savannah River Site ranges from 6,700 to 250,000 curies/cubic-meter. Finally, spent fuel aged 10 to 100 years would range from 105,000 to 2.7 million curies/cubic-meter (**Appendix, Table A-3**). These comparisons are for illustrative purposes only, as the radioactive constituents among the examples are different.

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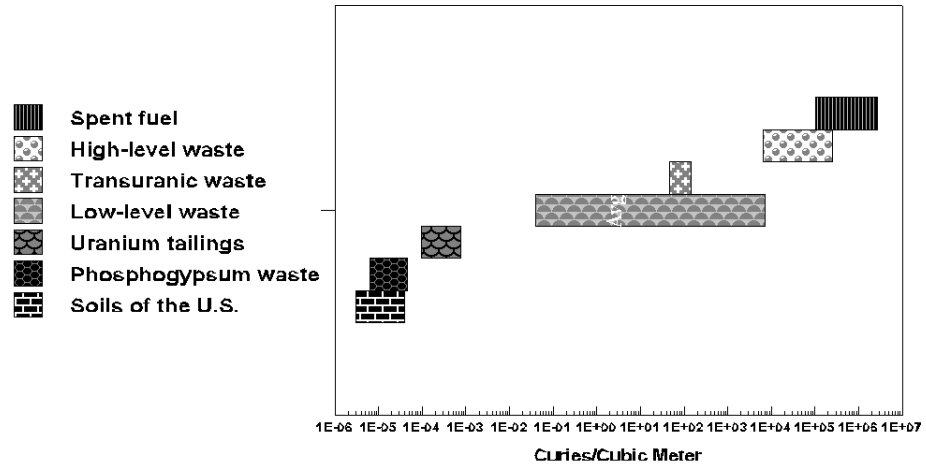
[7] U.S. Government Accounting Office, *Radiation Standards — Scientific Basis Inconclusive, and EPA and NRC Disagreement Continues* (GAO/RCED-00-152), June 2000.

Figure 1. Comparison of Radioactive Wastes



Notes:

Spent Fuel - BWR and PWR fuel rod assemblies 10 to 100 years decay time. Upper range of 2.67 x 10^{6} for 14 year BWR to lower range of 1.05 x 10^{5} for 100 year PWR. Source: Table A-13 of Appendix A to Yucca Mt. EIS ,and Appendix C to "Investigation of Nuclide Importance to Functional Requirements Related to Transport and Long-Term Storage of LWR Spent Fuel" (ORNL/TM/12742 - 1995).
High-level waste - Savannah River Site Vitrified HLW. Source: Personal Communication with W. Pearson, USDOE Savannah River.
Transuranic waste - 47 Ci/m3 for contact handled-TRU, 143 Ci/m3 for remote handled-TRU. Source: Table 1. of "The Waste Isolation Pilot Plant ," National Research Council (1996).
Low-level waste - Average based on Table 1 of "Commercial Gross Volume and Activity Distribution in Disposal of Low-Level and Mixed Low-Level Radioactive Waste During 1990" (DOE/EH-0332p, August 1993). Upper and lower limits of SR-90 Table 2 of 10 CFR 61.55.
Uranium tailings - (11e.(2) byproduct material) ranges from 9.72 x10^{-5} Ci/m3 at Maybell Mill Site Moffat County, Co. to 7.48 x10^{-4} at Salt Lake City Mill Site, Salt Lake County, Ut. Source: Summary Table of "Remediation of UMTRCA Title I Uranium Mill Sites Under the UMTRCA Project." EIA (December 31, 1999). [http://www.eia.doe.gov/cneaf/nuclear/page/umtra/title1sum.html].
Phosphogypsum waste -(Technologically Enhanced Naturally Occurring Radioactive Material) Caluclated average of 6.5 to 45 x 10^{-6} Ci/m^{3} based on 7.3 to 36.7 x 10^{-12} Ci/g. Source: Summary Table. U.S. EPA TENORM. [http://www.epa.gov/radiation/tenorm/sources_table.htm.] and density range of 888 to 1130 kg/m3 for Type 65 Florida phosphogypsum [http://www.agrium.com/1342.cfm].
Soils of the U. S. - Range from 3 to 40 x 10^{-6} Ci/m3. Source: Personal communication with J.K Otton, USGS.

Definitions of various radioactive wastes are summarized in **Table 2** along with applicable legislative provisions. More detailed descriptions of the wastes and the processes that generate the wastes are provided further below.

Table 2. Legislative and Regulatory Reference to Waste Definitions

Definition	Reference
Spent Nuclear Fuel (SNF) . . . withdrawn from a nuclear reactor following irradiation	Nuclear Waste Policy Act of 1982, 42 U.S.C. 10101
High-Level Waste (HLW) . . . highly radioactive material from reprocessing spent nuclear fuel	Nuclear Waste Policy Act of 1982, 42 U.S.C. 10101
Radioactive Waste Incidental to Reprocessing . . . reclassified waste stream that would otherwise be considered high-level due to its source or concentration	Defense Authorization Act for Fiscal Year 2005, P.L. 108-375
Transuranic Waste (TRU) . . . man-made elements above atomic number 92	Atomic Energy Act of 1954, 42 U.S.C. 2014
Surplus Weapons-Usable Plutonium	Non-Proliferation and Export Control Policy, PDD/NSC 13 1993
Low-Level Radioactive Waste (LLRW) . . . not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material	Low-Level Radioactive Waste Policy Amendments Act of 1985, P. L. 99-240
Class A, Class B, Class C Waste *Greater than Class C* (GTCC)	Licensing Requirements for Land Disposal of Radioactive Waste, 10 C.F.R. 61.55
Mixed Low Level Radioactive and Hazardous Waste . . . low-level radioactive waste under LLRWA and hazardous chemicals regulated under RCRA	Low-Level Radioactive Waste Policy Act of 1985 — 42 U.S.C. 2021b & Resource Conservation and Recovery Act of 1976 — 42 U.S.C. 6901
Uranium Mill Tailings . . . by-product material . . . naturally occurring radioactive material and uranium ore mill tailings	Uranium Mill Tailings Radiation Control Act of 1978 — 42 U.S.C. 7901
Depleted Uranium Hexafluoride . . . the source material uranium in which the isotope U-235 is less than 0.711 percent of the total uranium present	10 C.F.R. 40.4 — Domestic Licensing of Source Material

Spent Nuclear Fuel

Currently, 104 commercial nuclear power reactors are licensed by the NRC to operate in 31 states.[8] These reactors are refueled on a frequency of 12 to 24 months. A generic Westinghouse-designed 1,000-megawatt pressurized-water reactor (PWR) operates with 100 metric tons of nuclear fuel. During refueling, approximately one-third of the fuel (spent nuclear fuel) is replaced. The spent fuel is moved to a storage pool adjacent to the reactor for thermal cooling and decay of short-lived radionuclides.

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[8] 69 pressurized water reactors (PWR) and 35 boiling water reactors (BWR): *U.S. Nuclear Reactors*, U.S. DOE, Energy Information Administration, at [http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactsum.html].

Due to the limited storage pool capacity at some commercial reactors, some cooled spent fuel has been moved to dry storage casks. The NRC has licensed 30 independent spent fuel storage installations (ISFSI)for dry casks in 23 states.[9] Fuel debris from the 1979 Three Mile Island reactor accident has been moved to interim storage at the Idaho National Laboratory (INL). General Electric Company (GE) operates an independent spent fuel storage installation (Morris Operation) in Morris Illinois. A group of eight electric utility companies has partnered as Private Fuel Storage, LLC with the Skull Valley Band of Goshute Indians, and applied for an NRC license to build and operate a temporary facility to store commercial spent nuclear fuel on the Indian reservation in Skull Valley, Utah.

DOE spent fuel originated from nuclear weapons production, the naval reactor program, and both domestic and foreign research reactor programs. DOE spent fuel remains in interim storage at federal sites in Savannah River, South Carolina; Hanford, Washington; INL; and Fort St. Vrain, Colorado.[10]

In contrast to commercial reactors, naval reactors can operate without refueling for up to 20 years. [11] As of 2003, 103 naval reactors were in operation, and nearly as many have been decommissioned from service. Approximately 65 metric tons heavy metal (MTHM) of spent-fuel have been removed from the naval reactors. Until 1992, naval spent fuel had been reprocessed for weapons production, and since then has been transferred to INL for interim storage.

The planned Yucca Mountain repository is scheduled to receive 63,000 MTHM commercial spent nuclear fuel, and 2,333 MTHM of DOE spent-fuel.[12] The NWPA prohibits disposing of more than the equivalent of 70,000 MTHM in the first repository until a second is constructed.

The Energy Information Administration reported an aggregate total 47,023.4 MTHM discharged from commercial rectors over the period of 1968 to 2002.[13] Of the total, 46,268 MTHM is stored at reactor sites, and the balance of 755.4 MTHM is in stored away from reactor sites.

CRS obtained and compiled raw data from EIA on spent fuel discharged by commercial reactor operators to the end of 2002, and data on spent fuel stored at the

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[9] U.S. NRC, *2004-2005 Information Digest*, Figure 42 — Licensed Operating Independent Spent Fuel Storage Installations.

[10] U.S. DOE Office of Civilian Radioactive Waste Management, *Appendix A, Final Environmental Impact Statement for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE/EIS-0250), February 2002.

[11] U.S DOE and Department of the Navy, *The United States Navy Nuclear Propulsion Program*, March 2003.

[12] *Appendix A — Final Environmental Impact Statement*.

[13] U.S. DOE Energy Information Administration, *Spent Nuclear Fuel Data, Detailed United States as of December 31, 2002*, at [http://www.eia.doe.gov/cneaf/nuclear/spent_fuel/ussnfdata.html].

DOE national laboratory and defense sites (as of 2003 year-end).[14] A combined total of 49,333 MTHM had been discharged by commercial- and defense-related activities at the end of 2002. Commercial reactor storage pools accounted for 41,564 MTHM, and ISFSIs accounted for 5,294 MTHM. The balance was made up by 2,475 MTHM of federal spent fuel stored at national laboratories, defense sites, and university research reactors.[15] CRS's figures differ from EIA's in several respects: EIA compiles only commercial spent fuel data, combines data on reactor storage pool and dry storage at the reactor facility site, and identifies non-reactor site spent fuel as "away from reactor site" storage.[16] The data are geographically presented in **Figure 2** and summarized in **Table 3**.

At the end of 1998, EIA reported 38,418 MTHM of spent fuel discharged.[17] Based on 47,023 MTHM discharged at the end of 2002, CRS estimates that commercial reactor facilities discharge an average 2152 MTHM of spent fuel annually. On that basis, CRS estimates 53,637 MTHM of spent fuel had been discharged at the end of 2004.

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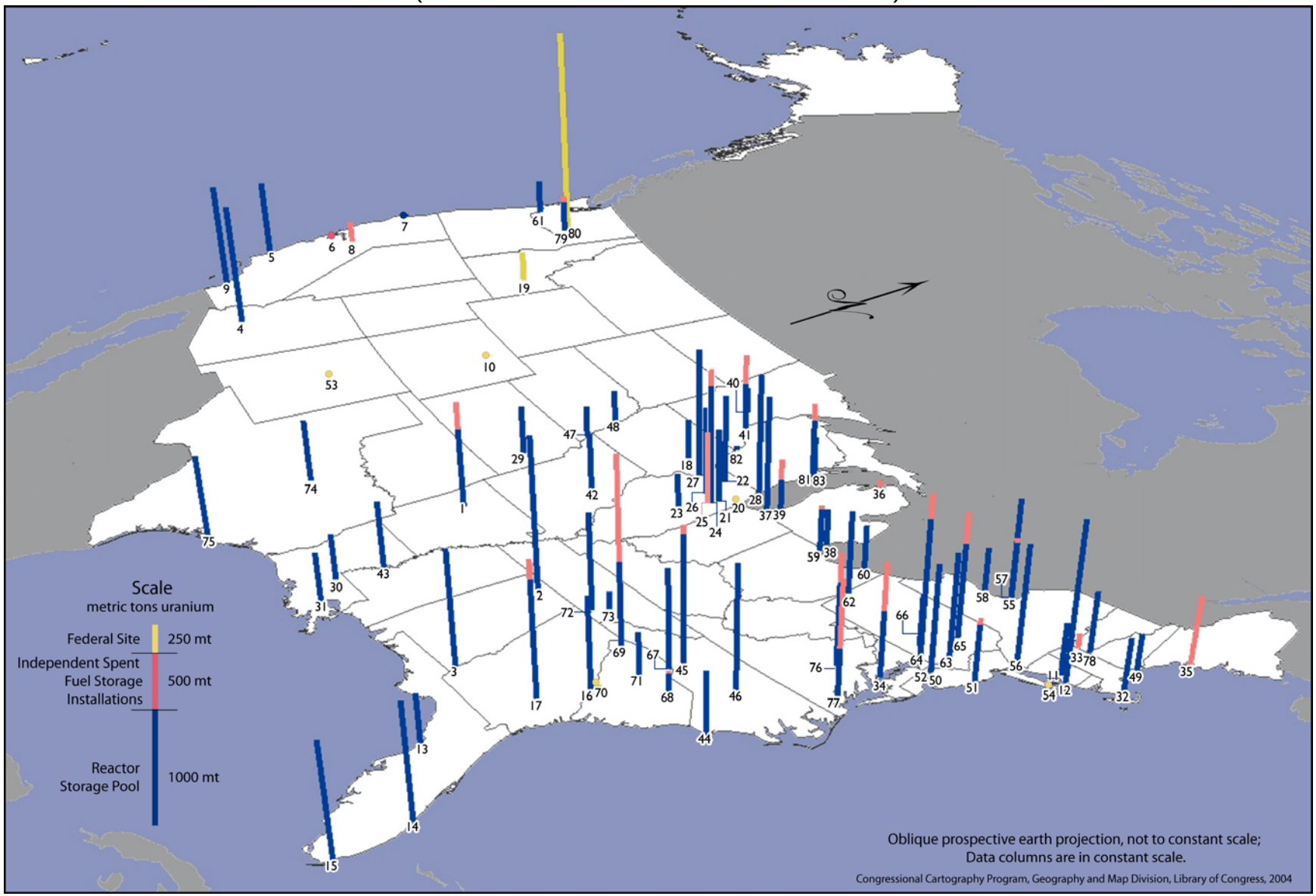
[14] U.S. DOE Energy Information Administration, *Form RW-859, "Nuclear Fuel Data" (2002)*

[15] Idaho National Engineering and Environmental Laboratory INTEC Programs Division

[16] Mostly General Electric's Morris facility, and the Fort St. Vrain High Temperature Gas Reactor facility in DOE caretaker status.

[17] U.S. DOE Energy Information Administration, *Prior Years 1998 Table*, at [http://www.eia.doe.gov/cneaf/nuclear/spent_fuel/ussnfdata.html].

Figure 2. Federal Sites, Commercial Reactor Storage Pools, and Independent Spent Fuel Storage Installations
(numbered labels refer to facilities in Table 3)



Source: U.S. DOE National Laboratories as of 2003 year end, and U.S. DOE EIA Form RW-859 as of 2002 year end.

Table 3. Federal Site, Commercial Reactor Pool, and Independent Spent Fuel Storage

Facility	St	T	Assembly	MTHM
1. Arkansas Nuclear One	AK	P	1,517	666.7
		I	552	241.4
2. Browns Ferry Nuclear Plant	AL	P	6,696	1,230.2
3. J M Farley Nuclear Plant	AL	P	2,011	903.8
4. Palo Verde Nuclear Generating Station	AZ	P	2,747	1,157.8
5. Diablo Canyon Power Plant	CA	P	1,736	760.9
6. GE Vallecitos Nuclear Center	CA	I	0	0.2
7. Humboldt Bay Power Plant	CA	P	390	28.9
8. Rancho Seco Nuclear Generating Sta	CA	I	493	228.4
9. San Onofre Nuclear Generating Station	CA	P	2,490	1,013.3
10. Fort St. Vrain Power Station	CO	F	1,464	14.7
11. Connecticut Yankee Atomic Power Co	CT	P	1,019	412.3
12. Millstone Nuclear Power Station	CT	P	4,558	1,227.9
13. Crystal River Nuclear Power Plant	FL	P	824	382.3
14. St. Lucie Nuclear Power Plant	FL	P	2,278	870.7
15. Turkey Point Station	FL	P	1,862	851.7
16. AW Vogtle, Jr. Electric Gen Plant	GA	P	1,639	720.8
17. EL Hatch Nuclear Plant	GA	P	5,019	909.3
		I	816	151.2
18. D Arnold Energy Center	IA	P	1,912	347.9
19. Idaho National Eng & Env Lab	ID	F	93,705	300.2
20. Argonne National Lab East	IL	F	78	0.1
21. Braidwood Generating Station	IL	P	1,485	628.7
22. Byron Generating Station	IL	P	1,786	756.4
23. Clinton Power Station	IL	P	1,580	288.8
24. Dresden Generating Station	IL	P	5,698	1,009.2
		I	1,155	146.9
46. Shearon Harris Nuclear Power Plant	NC	P	3,814	964.5
47. Cooper Nuclear Station	NE	P	1,537	278.6
48. Fort Calhoun Nuclear Station	NE	P	839	305.0
49. Seabrook Nuclear Station	NH	P	624	287.2
50. Hope Creek Generating Station	NJ	P	2,376	431.5
51. Oyster Creek Generating Station	NJ	P	2,556	455.9
		I	244	47.6
52. Salem Nuclear Generating. Station	NJ	P	1,804	832.7
53. Sandia National Laboratory	NM	F	503	0.3
54. Brookhaven National Laboratory	NY	F	40	0.0
55. JA Fitzpatrick Nuclear Power Plant	NY	P	2,460	446.5
		I	204	37.2
56. Indian Point Energy Center	NY	P	2,073	903.6
57. Nine Mile Point Nuclear Station	NY	P	4,456	801.6
58. R E Ginna Nuclear Power Plant	NY	P	967	357.4
59. Davis-Besse Nuclear Power Station	OH	P	749	351.3
		I	72	33.9
60. Perry Nuclear Power Plant	OH	P	2,088	378.4
61. Trojan Nuclear Power Plant	OR	P	780	358.9
62. Beaver Valley Power Station	PA	P	1,456	672.9
63. Limerick Generating Station	PA	P	4,601	824.0
64. Peach Bottom Atomic Power Sta	PA	P	5,905	1,062.7
		I	1,020	190.3
65. Susquehanna Steam Electric Station	PA	P	4,240	738.4
		I	1,300	238.5
66. Three Mile Island Nuclear Station	PA	P	898	416.1
67. Catawba Nuclear Station	SC	P	1,780	782.4

Facility	St	T	Assembly	MTHM
25. General Electric Morris Op	IL	I	3,217	674.3
26. LaSalle County Generating Station	IL	P	4,106	744.6
27. Quad Cities Generating Station	IL	P	6,116	1,106.5
28. Zion Generating Station	IL	P	2,226	1,019.4
29. Wolf Creek Generating Station	KS	P	925	427.3
30. River Bend Station	LA	P	2,148	383.9
31. Waterford Generating Station	LA	P	960	396.4
32. Pilgrim Nuclear Station	MA	P	2,274	413.9
33. Yankee Rowe Nuclear Power Station	MA	I	533	127.1
34. Calvert Cliffs Nuclear Power Plant	MD	P	1,348	518.0
		I	960	368.1
35. Maine Yankee Atomic Power Plant	ME	I	1,434	542.3
36. Big Rock Point Nuclear Plant	MI	I	441	57.9
37. D C Cook Nuclear Plant	MI	P	2,198	969.0
38. Enrico Fermi Atomic Power Plant	MI	P	1,708	304.6
39. Palisades Nuclear Power Station	MI	P	649	260.7
		I	432	172.4
40. Monticello Nuclear Generating Plant	MN	P	1,342	236.1
41. Prairie Island Nuclear Gen. Plant	MN	P	1,135	410.3
		I	680	262.3
42. Callaway Nuclear Plant	MO	P	1,118	479.0
43. Grand Gulf Nuclear Station	MS	P	3,160	560.2
44. Brunswick Steam Electric Plant	NC	P	2,227	477.4
45. W B McGuire Nuclear Station	NC	P	2,232	1,001.1
68. HB Robinson Steam Electric Plant	SC	P	344	147.9
		I	56	24.1
69. Oconee Nuclear Station	SC	P	1,419	665.8
		I	1,726	800.4
70. Savannah River Defense Site	SC	F	9,657	28.9
71. VC Summer Nuclear Station	SC	P	812	353.9
72. Sequoyah Nuclear Power Plant	TN	P	1,699	782.6
73. Watts Bar Nuclear Plant	TN	P	297	136.6
74. Comanche Peak Steam Electric Station	TX	P	1,273	540.7
75. South Texas Project	TX	P	1,254	677.8
76. North Anna Power Station	VA	P	1,410	652.7
		I	480	220.8
77. Surry Power Station	VA	P	794	365.4
		I	1,150	524.2
78. Vermont Yankee Generating Station	VT	P	2,671	488.4
79. Columbia Generating Station	WA	P	1,904	333.7
		I	340	61.0
80. Hanford Defense Site	WA	F	110,140	2,128.9
81. Kewaunee Nuclear Power Plant	WI	P	904	347.6
82. La Crosse Nuclear Generating. Station	WI	P	333	38.0
83. Point Beach Nuclear Plant	WI	P	1,353	507.4
		I	360	144.1
84. University Research & Domestic Training Reactors		F	4,834	1.7

Totals by Type (T):

Commercial Reactor Pool	P	145,589	41,564.1
National Lab & Defense Site Storage	F	220,421	2,474.8
Commercial ISFSI	I	18,630	5,294.6
Combined Total		384,640	49,333.4

High-Level Radioactive Waste

NWPA defines high-level waste as "liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations," and "other highly radioactive material" that NRC determines requires permanent isolation.[18] Most of the United States' high-level waste inventory was generated by DOE (and former AEC) nuclear weapons programs at the Hanford, INL, and Savannah River Sites. A limited quantity of high-level waste was generated by commercial spent fuel reprocessing at the West Valley Demonstration Project in New York.[19]

Weapons-production reactor fuel, and naval reactor spent fuel were processed to remove special nuclear material (plutonium and enriched uranium). Reprocessing generated highly radioactive, acidic liquid wastes that generated heat.[20] As spent fuel reprocessing ceased in 1992, high-level waste is no longer generated. The wastes that were previously generated continue to be stored at Hanford, INL, and Savannah River, where they will eventually be processed into a more stable form for disposal in a deep geologic repository.

The Hanford Site generated approximately 53 million gallons of high-level radioactive and chemical waste now stored in 177 underground carbon-steel tanks.[21] Some strontium and cesium had been separated out and encapsulated as radioactive source material, then commercially leased for various uses. The Savannah River Site generated about 36 million gallons of high-level waste that it stored in 53 underground carbon-steel tanks.[22] Both the Hanford and Savannah River Sites had to neutralize the liquid's acidity with caustic soda or sodium nitrate to condition it for storage in the carbon-steel tanks. (The neutralization reaction formed a precipitate which collected as a sludge on the tank bottom; see the discussion of

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[18] "Permanent isolation" is left undefined by the NWPA.

[19] From 1966 to 1972, Nuclear Fuel Services operated a commercial nuclear fuel reprocessing plant at the Western New York Nuclear Services Center under contract to the State of New York. During the six years of operation, the plant processed approximately 640 metric tons of spent nuclear fuel, about three-fourths of which was provided by the AEC (60 percent of the total was from U. S. defense reactors). The plant generated approximately 2.3 million liters (600,000 gallons) of liquid high-level waste that was stored in underground tanks. In 1972, nuclear fuel reprocessing operations were discontinued. The liquid high-level radioactive waste produced during reprocessing was stored in underground steel tanks. New York State Energy Research and Development Authority, at [http://www.nyserda.org/westval.html].

[20] U.S. DOE, *Integrated Data Base Report — 1995: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, Rev. 12 (DOE/RW-0006), December 1996.

[21] U.S. DOE Hanford Site, *Electricity, Water, and Roads for Hanford's Future Vitrification Plant Completed Ahead of Schedule and Under Budget*, press release, September 18, 2001, at [http://www.hanford.gov/press/2001/orp/orp-091801.html].

[22] U.S. DOE Savannah River Site, *Spent Nuclear Fuel Program Fact Sheet*, at [http://www.srs.gov/general/outreach/srs-cab/fuelfrm/facts1.htm].

waste-incidental-to- reprocessing below.) Savannah River has constructed and begun operating a defense-waste processing facility that converts high-level waste to a vitrified (glass) waste-form. The vitrified waste is poured into canisters and stored on site until eventual disposal in a deep geologic repository. A salt-stone byproduct will be permanently disposed of on site. Hanford has plans for a similar processing facility.

INL generated approximately 300,000 gallons of high-level waste through 1992 by reprocessing naval reactor spent fuel, and sodium-bearing waste from cleaning contaminated facilities and equipment.[23] The liquid waste had originally been stored in 11 stainless steel underground tanks. All of the liquid high-level waste has been removed from five of the 11 tanks and thermally converted to granular (calcine) solids. Further treatment is planned, and INL is also planning a waste processing facility similar to Savannah River's vitrification plant.

West Valley's high-level waste has been vitrified and removed from the site. The vitrification process thermally converts waste materials into a borosilicate glass-like substance that chemically bonds the radionuclides. The vitrification plant is being decommissioned. The Hanford Site and INL are planning similar vitrification plants.

High-level waste is also considered a mixed waste because of the chemically hazardous substances it contains, which makes it subject to the environmental regulations under the Resource Conservation and Recovery Act (RCRA).

Waste Incidental to Reprocessing

DOE policy in Order 435.1 refers to *waste incidental to reprocessing* in reclassifying a waste stream that would otherwise be considered high-level due to its source or concentration.[24] DOE's Implementation Guide to the Order states that "DOE Manual 435.1-1 is not intended to create, or support the creation of, a new waste type entitled incidental waste." The waste stream typically results from reprocessing spent fuel. DOE has determined that under its regulatory authority the incidental-to-processing waste stream can be managed according to DOE requirements for transuranic or low-level waste, if specific criteria are met.

The DOE evaluation process for managing spent-fuel reprocessing wastes considers whether (1) the "wastes are the result of reprocessing plant operations such as contaminated job wastes including laboratory items such as clothing, tools and equipment,"[25] and (2) key radionuclides have been removed in order to permit downgrading the classification to either low-level waste or transuranic waste.

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[23] U.S. DOE Idaho National Laboratory/ Idaho Nuclear Technology and Engineering Center — *Cleanup Status*, at [http://www.inel.gov/ environment/intec/].

[24] U.S. DOE, M 435.1-1 *Radioactive Waste Management Manual of 7-09-99*, and G 435.1-1 *Implementation Guide for DOE M 435.1-1*.

[25] Notice of Proposed Rulemaking (34 FR 8712) for Appendix D 10 C.F.R. 50.

Evaluation process wastes include large volumes of low-activity liquid wastes (separated from high-level waste streams), a grout or salt-stone solid form, and high-level waste residues remaining in storage tanks. DOE's evaluation process at the Savannah River Site resulted in capping the residue left in high-level waste storage tanks with cement grout.

Public comments on the draft of Order 435.1 expressed the concern that potentially applicable laws do not define or recognize the principle of "incidental waste," or exempt high-level waste that is "incidental" to DOE waste management activities from potential NRC licensing authority.[26] In 2003, the Natural Resources Defense Council (NRDC) challenged DOE's evaluation process for Savannah River as scientifically indefensible, since no mixing occurred to dilute the residue's activity when capping it with grout.[27] DOE countered that through the waste-incidental-to-reprocessing requirements of Order 435.1, key radionuclides have been removed from the tanks, and the stabilized residual waste does not exceed Class C low-level radioactive waste restrictions for shallow land burial.[28] Removing the residual waste would be costly and expose workers to radiologic risks, according to DOE.

In *NRDC v. Abraham*, the Federal District Court in Idaho ruled in 2003 that DOE violated the NWPA by managing wastes through the evaluation process in Order 435.1.[29] The Energy Secretary later asked the Congress for legislation clarifying DOE authority in determinations on waste-incidental-to-reprocessing at Hanford, Savannah River, and INL.[30] On November 5, 2004, the U.S. Court of Appeals for the Ninth Circuit vacated the district court's judgment and remanded the case with a direction to dismiss the action.[31]

Section 3116 (Defense Site Acceleration Completion) in the Ronald W. Reagan Defense Authorization Act of FY2005 (P.L. 108-375) specifies that the definition of the term "high-level radioactive waste" excludes radioactive waste from reprocessed spent fuel if (1) the Energy Secretary in consultation with the NRC determines the waste has had highly radioactive radionuclides removed to the maximum extent practical, and (2) the waste does not exceed concentration limits for Class C low-level waste. Section 3117 (Treatment of Waste Material) authorizes $350 million for DOE's High Level Waste Proposal to accelerate the cleanup schedule for the Hanford, Savannah River, and INL. For further information on this subject, refer to

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[26] U.S. DOE Office of Environmental Management, *Summary of Public Comments on DOE Order 435.1, Radioactive Waste Management*, at [http://web.em.doe.gov/em30/pubsum16.html].

[27] Letter from Natural Resources Defense Council to the Honorable J. Dennis Hastert, August 19, 2003.

[28] Second Declaration of Jessie Roberson in NRDC v. Abraham, 271 F. Supp. 2nd 1260 (D. Id. 2003).

[29] NRDC v. Abraham, 271 F. Supp. 2nd 1260 (D. Id. 2003).

[30] "DOE seeks nuclear waste clarification to reaffirm HLW disposal strategy," *Nuclear Fuel*, The McGraw-Hill Companies, August 19, 2003.

[31] No. 03-35711 United States Court of Appeals for the Ninth Circuit 2004 U.S.

CRS Report RS21988, *Radioactive Tank Wastes: Disposal Authority in the Ronald W. Reagan National Defense Authorization Act for FY2005*.

Transuranic Waste

The Atomic Energy Act (42 U.S.C. 2014) defines transuranic (TRU) waste as material contaminated with elements having atomic numbers greater than uranium (92 protons) in concentrations greater than 10 nanocuries/gram . The DOE (with other federal agencies) revised the minimum radioactivity defining transuranic waste from 10 nanocuries/gram to greater than 100 nanocuries/gram in 1984.

Transuranic elements are artificially created in a reactor by irradiating uranium. These elements include neptunium, plutonium, americium, and curium. Many emit alpha particles and have long half-lives.[32] Americium has commercial use in smoke detectors, and plutonium produces fission energy in commercial power reactors.

Transuranic waste is generated almost entirely by DOE (and former AEC) defense-related weapons programs. The waste stream results from reprocessing irradiated fuel to remove plutonium-239 or other transuranic elements, and from fabricating nuclear weapons and plutonium-bearing reactor fuel. The waste may consist of plutonium-contaminated debris (such as worker clothing, tools, and equipment), sludge or liquid from reprocessing, or cuttings and scraps from machining plutonium.

In 1970, the former AEC determined that the long half-life and alpha emissions associated with transuranic waste posed special disposal problems. This prompted the decision to stop the practice of burying TRU waste in shallow landfills as a low-level waste.[33]

DOE distinguishes "retrievably stored" transuranic waste from "newly generated" waste. Waste buried prior to 1970 is considered irretrievable and will remain buried in place. Since 1970, transuranic waste has been packaged (e.g., metal drums, wood or metal boxes) and retrievably stored in above-ground facilities such as earth-mounded berms, concrete culverts, buildings, and outdoor storage pads. Waste that has been retrieved or will be retrieved, and then repackaged for transportation and disposal, is classed as newly generated waste.[34]

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[32] Arjun Makhijani and Scott Saleska, *High-level Dollars, Low-Level Sense*, The Apex Press, New York, 1992.

[33] U.S. DOE, I*ntegrated Data Base Report-1995: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics* (DOE/RW-0006, Rev.12), December, 1996.

[34] The National Academies Board on Radioactive Waste Management, *Characterization of Remote-Handled Transuranic Waste for the Waste Isolation Pilot Plant, Interim Report*;, National Academy Press, Washington, D.C., 2001.

The Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (P.L. 96-164) directed the Energy Secretary to consult and cooperate with New Mexico in demonstrating the safe disposal of defense radioactive wastes. The Waste Isolation Pilot Plant Land Withdrawal Act (P.L. 102-579 as amended by P.L. 104-211) limited disposal acceptance to transuranic waste with a half-life greater than 20 years and radioactivity greater than 100 nanocuries/gram. The WIPP Act further defined transuranic waste in terms of "contact-handled transuranic waste" having a surface dose less than 200 millirem per hour, and "remote-handled transuranic waste" having a surface dose rate greater than 200 millirem/hour. The WIPP facility (near Carlsbad, New Mexico) began accepting transuranic waste in 1999.

The Resource Conservation and Recovery Act of 1976 (42 U.S.C. 6901) imposed additional disposal requirements on transuranic waste mixed with hazardous constituents. Mixed radioactive and hazardous waste is a separate classification discussed further below.

The Energy and Water Development Appropriations Act for 2005 (P.L. 108-447) and appropriation acts for some prior years precluded the WIPP facility from disposing of transuranic waste containing plutonium in excess of 20%, as determined by weight.

Surplus Weapons-Usable Plutonium

The Atomic Energy Act defines "special nuclear material" as plutonium, uranium enriched in isotopes 233 or 235, and any other material the NRC determined as special nuclear material. Special nuclear material is important in weapons programs and as such has strict licensing and handling controls. Under President Clinton's 1993 Nonproliferation and Export Control Policy, 55 tons of weapons-usable plutonium was declared surplus to national security needs.[35] DOE plans to use surplus plutonium in mixed oxide fuel for commercial power reactors.[36] Plutonium not suitable for mixed oxide fuel fabrication is destined for repository disposal. The special facility constructed to reprocess the surplus would generate transuranic waste and low-level radioactive waste streams. Spent mixed oxide fuel would be disposed of in the same manner as conventional commercial spent fuel in an NRC-licensed deep geologic repository.

Low-Level Radioactive Waste

The Low-Level Radioactive Waste Policy Act of 1980 (P.L. 96-573) defines "low-level radioactive waste" as radioactive material that is not high-level radioactive waste, spent nuclear fuel, or byproduct material, and radioactive material that the Nuclear Regulatory Commission (NRC) classifies as low-level radioactive

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[35] U.S. DOE Office of Fissile Materials Disposition, *Surplus Plutonium Disposition Final Environmental Impact Statement* (TIC:246358), 1999.

[36] U.S. DOE, *Record of Decision for the Surplus Plutonium Final Environmental Impact Statement, 65 FR 1608*; January 11, 2000.

waste consistent with existing law. Low-level waste is classified as A, B, C, or Greater than Class C in 10 C.F.R. 61.55 — Waste Classification. These classes are described further below. Commercial low-level waste is disposed of in facilities licensed under NRC regulation, or NRC-compatible regulations of "agreement states."

Low-level radioactive waste is generated by nuclear power plants, manufacturing and other industries, medical institutions, universities, and government activities. Much of the nuclear power plant waste comes from processes that control radio-contaminants in reactor cooling water. These processes produce wet wastes such as filter sludge, ion-exchange resins, evaporator bottoms, and dry wastes. Institutions such as hospitals, medical schools, research facilities, and universities generate wastes of significantly differing characteristics. Industrial generators produce and distribute radionuclides, and use radioisotopes for instruments and manufacturing processes. The General Accounting Office (now Government Accountability Office) reported that of the 12 million cubic feet of low-level waste disposed of in 2003, 99% constituted Class A.[37]

The NRC classifies low-level waste using two tables: one for long-lived radionuclides, and one for short-lived. Long-lived and short-lived refer to the length of time for radioactive decay. For regulatory purposes, the dividing line between short-lived and long-lived is a half-life of 100 years. The radionuclides included as long-lived are: carbon-14, nickel-59, niobium-94, technetium-99, iodine-129, plutonium-241, and curium-242. The group "alpha emitting transuranic nuclides with half-lives greater than 5 years" is included in the long-lived table, as various isotopes of the group may have half-lives in the range of hundreds-of-thousand of years. The short-lived radionuclide table includes tritium (hydrogen-3), cobalt-60, nickel-63, strontium-90, and cesium-137. A group of unspecified "nuclides with half-lives less than 5 years" is included as short-lived.

Low-level waste generated by nuclear power plants results from the fission of uranium fuel, or the activation of the reactor components from neutrons released during fission. Trace amounts of uranium left on fuel rod surfaces during manufacturing are partly responsible for the fission products in the reactor cooling water.[38] Tritium (H-3) occasionally results from uranium fission, and from reactor cooling water using boron as a soluble control absorber.[39] The radionuclides carbon-14, nickel-53, nickel-59, and niobium-94 are created when stainless steel reactor components absorb neutrons. The radionuclides strontium-90, technetium-99, and cesium-137 are fission products of irradiated uranium fuel. The transuranic radionuclides are neutron-activation products of irradiated uranium fuel. Iodine-129 is found in radioactive wastes from defense-related government facilities and nuclear

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[37] U.S. GAO, *Low-Level Radioactive Waste — Disposal Availability Adequate in the Short Term, but Oversight Needed to Identify Any Future Shortfalls* (GAO-04-604), June 2004.

[38] U.S. DOE, *Appendix A, Final Environmental Impact Statement.*

[39] Raymond, L. Murray, Chapter 16 of *Understanding Radioactive Waste*, Battelle Press, 2003.

fuel cycle facilities; if released into the environment, its water solubility allows its uptake by humans, where it concentrates in the thyroid gland.[40]

Some of the short-lived radionuclides have specific industrial or institutional applications. These include cobalt-60, strontium-90, and cesium-137. Cobalt-60 is used in sealed sources for cancer radiotherapy and sterilization of medical products; its intense emission of high-energy gamma radiation makes it an external hazard, as well as an internal hazard when ingested. Strontium-90 is used in sealed sources for cancer radiotherapy, in luminous signs, in nuclear batteries, and in industrial gauging. Due to strontium's chemical similarity to calcium, it can readily be taken up by plants and animals, and is introduced into the human food supply through milk. Cesium-137 also is used in sealed sources for cancer radiotherapy, and due to its similarity to potassium can be taken up by living organisms.

Low-level waste classification ultimately determines whether waste is acceptable for shallow land burial in an NRC- or state-licensed facility. The four waste classes identified by 10 C.F.R. Section 61.55 on the basis of radionuclide concentration limits are:

- Class A: waste containing the lowest concentration of short-lived and long-lived radionuclides. Examples include personal protective clothing, instruments, tools, and some medical wastes. Also, waste containing any other radionuclides left unspecified by 10 C.F.R. 61.55 is classified as A.

- Class B: an intermediate waste classification that primarily applies to waste containing either short-lived radionuclides exclusively, or a mixture of short-lived and long-lived radionuclides in which the long-lived concentration is less than 10% of the Class C concentration limit for long-lived radionuclides.

- Class C: wastes containing long-lived or short-lived radionuclides (or mixtures of both) at the highest concentration limit suitable for shallow land burial. Examples include ion exchange resins and filter materials used to treat reactor cooling water, and activated metals (metal exposed to a neutron flux — irradiation — that creates a radioactive isotope from the original metal).

- Greater than Class C (GTCC): waste generally not acceptable for near-surface disposal. Greater than Class C wastes from nuclear power plants include irradiated metal components from reactors such as core shrouds, support plates, and core barrels, as well as filters and resins from reactor operations and decommissioning.

The physical form, characteristics, and waste stability requirements are summarized in **Table 4**.

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[40] U.S. EPA, *Facts about Iodine*, at [http://www.epa.gov/superfund/resources/radiation/pdf/iodine.pdf].

Table 4. Physical Form and Characteristics of Low-Level Waste

	Class A	Class B	Class C	Greater than Class C
Form	Trash, soil, rubble, depleted uranium, mildly contaminated equipment and clothing.	Reactor components, sealed radioactive sources, filters and resins from nuclear power plants.	Same as Class B but higher in radioactivity.	Reactor components and filter resins from reactor decommissioning.
Specific activity	near background to 700 Ci/m^3	0.04 to 700 Ci/m^3	44 to 7,000 Ci/m^3	Greater than Class C.
Maximum waste concentration basis	•100-year decay to acceptable hazard level* to an intruder	•100-year decay to acceptable hazard level* to an intruder.	•100-year decay exceeds acceptable hazard level* to an intruder. •500-year acceptable hazard level reached. •500-year protection provided by deeper disposal or intruder barriers.	Unspecified by regulation.
Waste containers	No special provisions, if waste is buried in a separate disposal cell.	Must be designed to be stable for 300 years.	Must remain stable for 300 years.	(Not applicable)
Special Disposal Provisions	Waste stabilization required if buried with Class B or C waste.	(Not applicable)	Barriers to intrusion required that must remain effective for 500 years where site conditions prevent deeper disposal.	Though generally not acceptable for near-surface disposal, regulation allows for disposal in near-surface facility if approved by NRC, or other wise must be disposed of in a geologic repository.

Ci/m^3: Curies/cubic-meter

* Acceptable hazard level to an intruder is based on maximum annual dose equivalent of 500 millirem (mrem) to the whole body of any member of the public — Sec. 61.42, and draft Generic Environmental Impact Statement for Part 61, NUREG-0782. Acceptable hazard level to the general population is based on maximum dose equivalent of 25 mrem to whole body, 75 millirems to thyroid, and 25 millirems to any organ of any member of the public.

Class A, B, and C wastes are candidates for near-surface disposal. The concept for near-surface disposal is: a system composed of the waste form, a trenched excavation, engineered barriers, and natural site characteristics. Through complex computer models, the licensee must demonstrate that the site and engineered features comply with the performance objectives in 10 C.F.R. Part 61. Generally Class A and B wastes are buried no greater than 30 meters (~100 feet). Class C waste must be buried at a greater depth to prevent an intruder from disturbing the waste after institutional controls have lapsed. The operation of a disposal facility was originally foreseen to last 20 to 40 years, after which it would be closed for stabilization period of 1 to 2 years, observed and maintained for 5 to 15 years, then transferred to active institutional control for 100 years.[41] At the time of licensing, funds had to be guaranteed by the state or licensee for the facility's long term care after closure. At present, no disposal facility exists for Greater than Class C Waste, though the DOE is in the initial phase of a process to identify disposal options.[42]

The Senate Committee on Energy and Natural Resources conducted a hearing in September 2004 to consider the potential shortage of low-level waste disposal sites.[43] The GAO had concluded in a 2004 report that no shortfall in disposal capacity appeared imminent, although the national low-level waste database that would be used to estimate the adequacy of future capacity was inaccurate.[44] The GAO recommended that the DOE stop reporting the database information, and added that Congress may wish to consider directing the Nuclear Regulatory Commission to report when the disposal capacity situation changes enough to warrant congressional evaluation.

Low-Level Waste Classification Tables

The NRC created two tables in 10 C.F.R 61.55 for classifying low-level waste on the basis of radionuclide concentration limits. Table 1 of the regulation applies to long-lived radionuclides, and Table 2 applies to short-lived (included as Figures A-1 and A-2 in the Appendix of this report). The concentration limits are expressed in units of "curies/cubic meter" or "nanocuries/gram" (the latter unit applying exclusively to the alpha-emitting transuranic radionuclides). **Figures 3** through **6** represent an illustrative guide to interpreting Tables 1 and 2; they are *not* intended, however, for actual waste classification purposes. The figures break down Tables 1 and 2 by long-lived, transuranic, short-lived and mixed long- and short-lived radionuclides. In the case of mixed radionuclides, the "sum-of-the-fractions" rule must be applied.

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[41] U.S. NRC, *Final Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste* (NURGEG-0945), November 1982.

[42] "DOE begins looking at options for disposal of GTCC radwaste," *Nuclear Fuels*, October 11, 2004.

[43] S. Hrg. 108-756, September 30, 2004.

[44] U.S. GAO, *Low-Level Radioactive Waste — Disposal Availability Adequate in the Short Term, but Oversight Needed to Identify Any Future Shortfalls* (GAO-04-604), June 2004.

Sum-of-the-Fractions Rule. Waste containing a mixture of radionuclides must be classified by applying the sum-of-the fractions rule. In the case of short-lived radionuclides — for each radionuclide in the mixture, calculate the fraction:

$$\frac{\textit{radionuclide-concentration}}{\textit{lowest-concentration- limit}}$$

then calculate the fractions' sum. If the sum-of-the-fractions is less than 1, the waste class is Class A. If the sum of the fractions is greater than 1, recompute each fraction using the upper concentration limits. If the fraction sum is less than 1, the waste is Class C; if greater than 1 then it is Greater than Class C. In the case of long-lived radionuclides, sum the fractions of each radionuclide concentration divided by the Column 1 concentration limits. If the resulting fraction sum is less than 1, the waste is Class A. If the fraction sum is greater than 1, recompute the fractions by applying the Column 2 concentration limits. If the sum is less than 1, the waste is Class B. If the sum is greater than 1, recompute again using the Column 3 limits. For example, consider a waste containing concentrations of long-lived radionuclides Sr-90 at 50 Ci/m^3 and Cs-137 at 22 Ci/m^3. Since the concentrations each exceed the values in Column 1 (0.04 and 1.0 respectively) of Chart 3 (Table 2 of Section 61.55), they must be compared to the concentration limits of Column 2. For Sr-90, the fraction 50/150 equals 0.33, for Cs-137 the fraction 22/44 equals 0.5. The resulting sum of the fractions (0.33 + 0.5) equals 0.83. Since the sum is less than 1.0, the waste is Class B.

Figure 3. Low-Level Waste Classification by Long-Lived Radionuclides

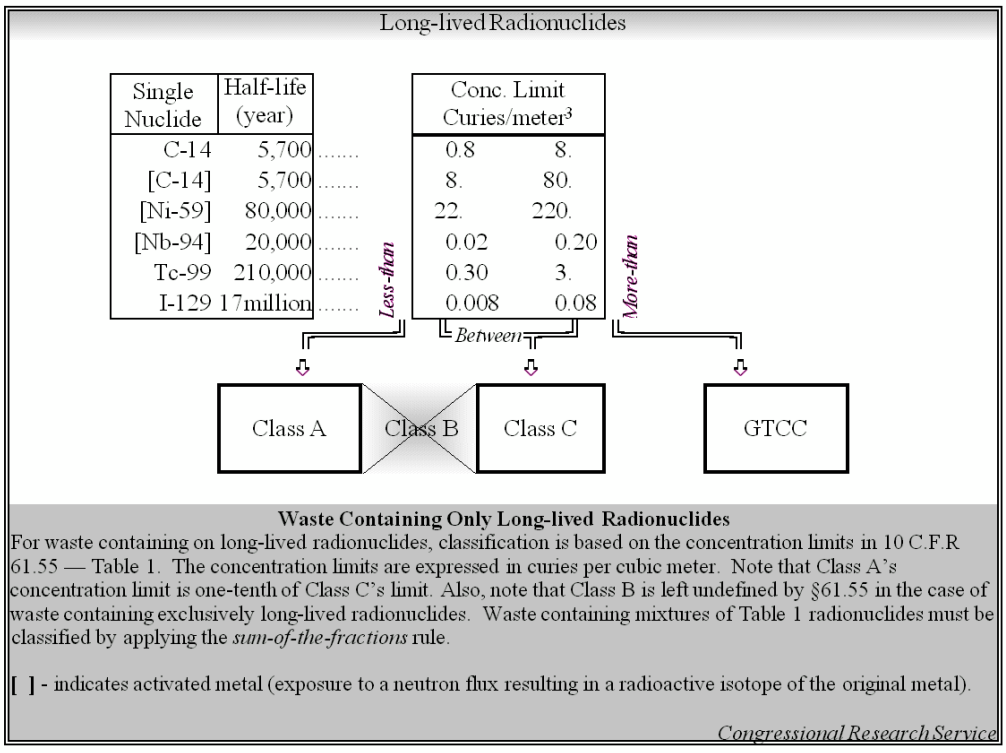


Figure 4. Low-Level Waste Classification by Transuranic Radionuclides

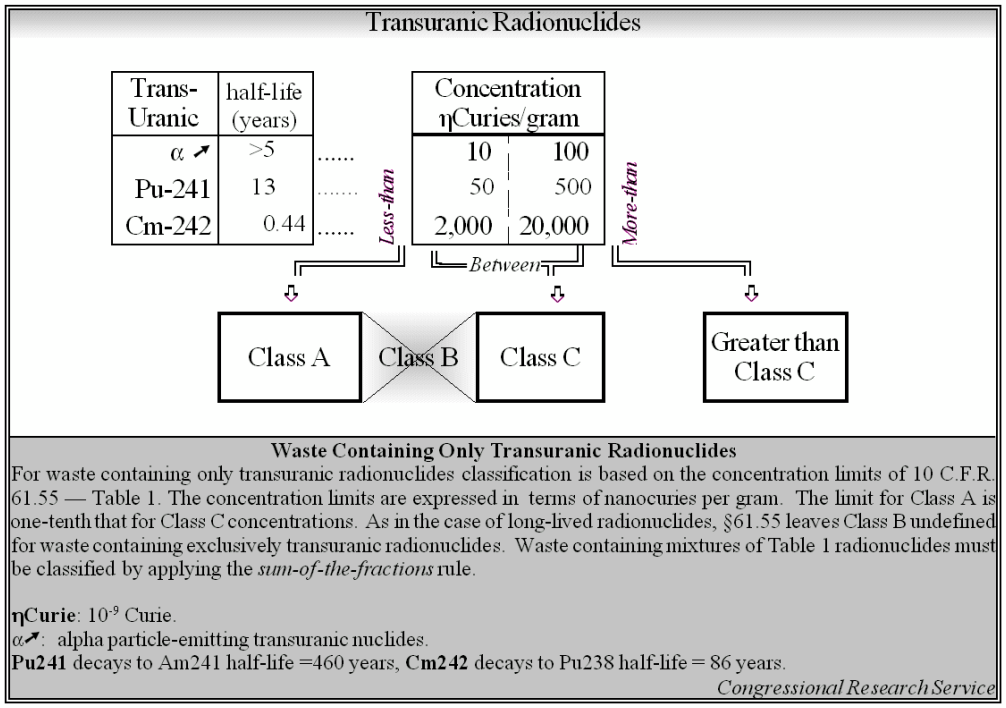


Figure 5. Low-Level Waste Classification by Short-Lived Radionuclides

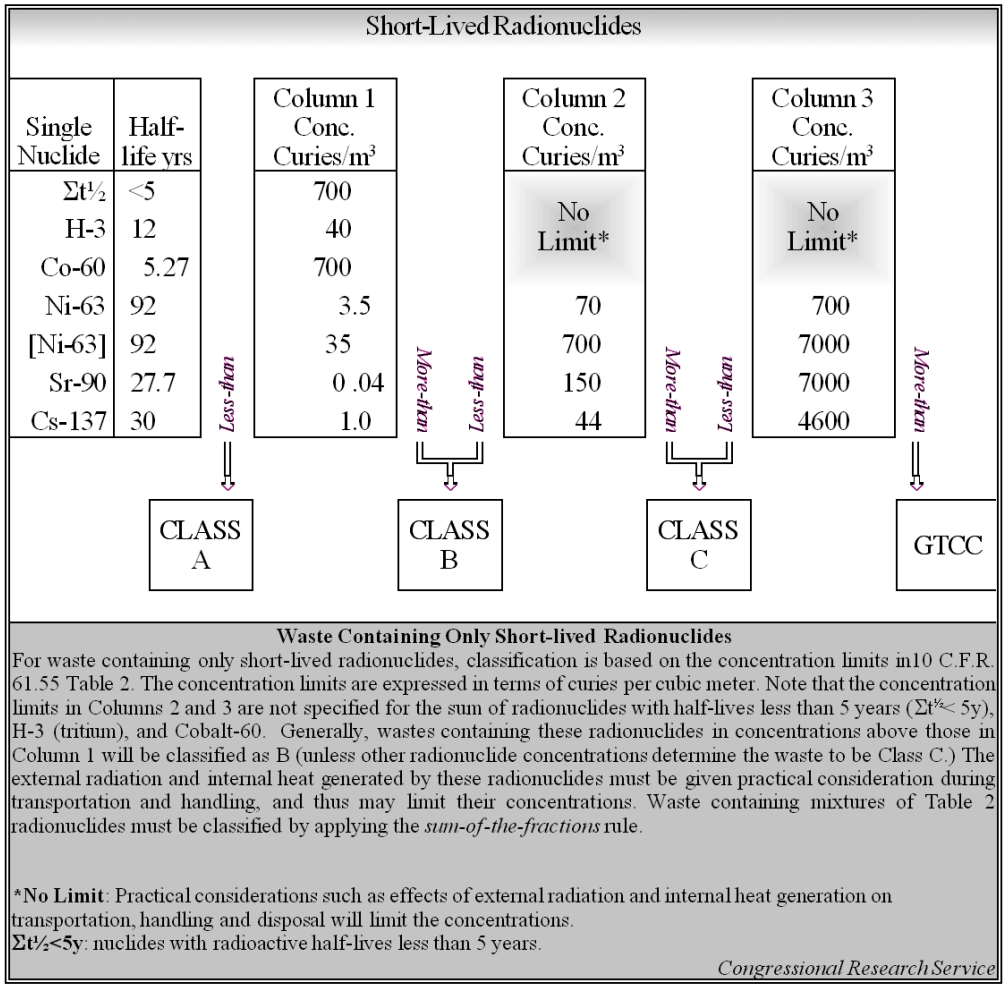
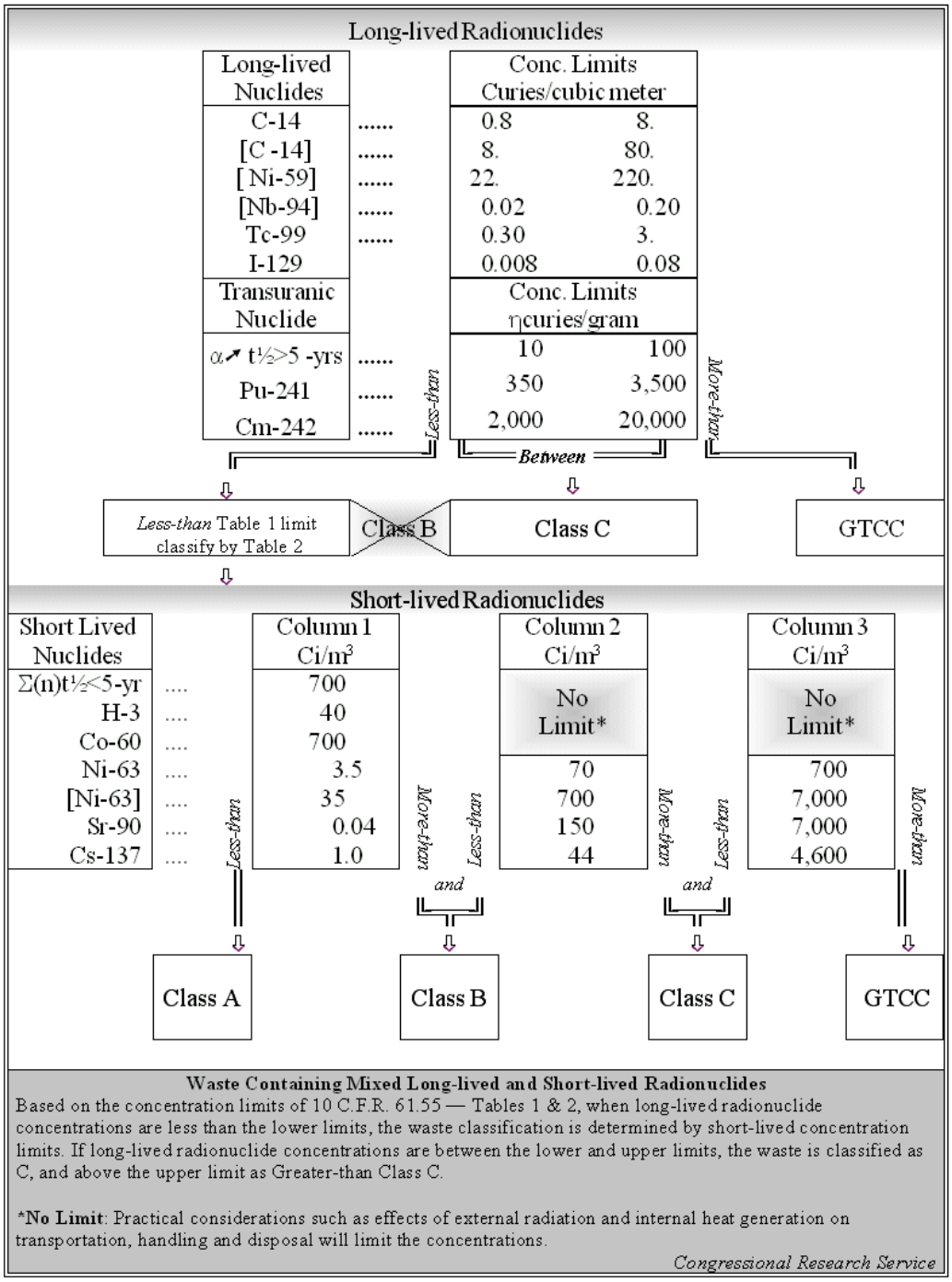


Figure 6. Low-Level Waste Classification by Mixed Long-Lived and Short-Lived Radionuclides



Mixed Low-Level Radioactive and Hazardous Waste

Mixed waste contains both concentrations of radioactive materials that satisfy the definition of low-level radioactive waste in the Low-Level Radioactive Waste Policy Act, and hazardous chemicals regulated under the Resource Conservation and Recovery Act (RCRA, 42 U.S.C. 6901). In general, facilities that manage mixed waste are subject to RCRA Subtitle C (Hazardous Waste) requirements for hazardous waste implemented by EPA (40 C.F.R. 124 and 260-270) or to comparable regulations implemented by states or territories that are authorized to implement RCRA mixed waste authority. The RCRA Subtitle C program was primarily developed for the states' implementation with oversight by EPA.

Depleted Uranium

Naturally occurring source material uranium contains uranium isotopes in the approximate proportions of: U-238 (99.3%), U-235 (0.7%), and U-234 (trace amount) by weight. Source material uranium is radioactive, U-235 contributing 2.2% of the activity, U-238 48.6%, and U-234 49.2% .[45] Depleted uranium is defined in 10 CFR 40.4 (Domestic Licensing of Source Material) as "the source material uranium in which the isotope U-235 is less than 0.711 % of the total uranium present." It is a mixture of isotopes U-234, U-235, and U-238 having an activity less than that of natural uranium.[46] Most of the DOE depleted uranium hexafluoride inventory has between 0.2% and 0.4% U-235 by weight.[47]

The former AEC began operating uranium enrichment plants in 1945 to produce U-235 enriched fuel for national defense and civilian nuclear reactors. Most commercial light-water reactors use uranium enriched 2%-5% with U-235.[48] As part of that enrichment process, uranium ore was converted to uranium hexafluoride (UF6) gas to facilitate U-235's separation, depleting the source material uranium of its U-235 isotope. DOE's inventory of depleted uranium hexafluoride (DUF6) is approximately 700,000 metric tons. The DUF6 is stored in metal cylinders at the three enrichment plant sites: Paducah, KY; Portsmouth, OH; and Oak Ridge, TN.

As part of DOE's DUF6 Management Program,[49] Oak Ridge National Laboratory (ORNL) conducted an assessment of converting the DUF6 to one of four stable forms: metallic (DU), tetrafluoride (DUF4), dioxide (DUO2) and triuranium

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[45] U.S. NRC, Natural Uranium, at [http://www.nrc.gov/reading-rm/basic-ref/glossary/natural-uranium.html].

[46] ANSI N7.2-1963 definition.

[47] U.S. DOE, Office of Environmental Management Depleted Uranium Hexafluoride Management Program, *Overview of Depleted Uranium Hexafluoride Management Program*, at [http://web.ead.anl.gov/uranium/pdf/DUF6MgmtOverviewFS.PDF].

[48] U.S. DOE National Nuclear Security Administration, *Nuclear Terms Handbook*, 2001.

[49] U.S. DOE, *Depleted UF6 Management*, at [http://web.ead.anl.gov/uranium/mgmtuses/index.cfm].

octaoxide (DU3O8).[50] ORNL considers the characteristics of the four forms suitable for disposal as low-level radioactive waste. The DU metal form has commercial and military uses (aircraft counterweights, shielding, armor, and munitions).

DOE has considered the environmental impacts, benefits, costs, and institutional and programmatic needs associated with managing its DUF6 inventory. In the 1999 Record of Decision for Long Term Management and Use of Depleted Uranium Hexafluoride,[51] DOE decided to convert the DUF6 to depleted uranium oxide, depleted uranium metal, or a combination of both. The depleted uranium oxide would be stored for potential future uses or disposal as necessary. Conversion to depleted uranium metal would be performed only when uses for the converted material were identified. DOE stated that it did not believe that long-term storage as depleted uranium metal and disposal as depleted uranium metal were reasonable alternatives. DOE has selected Uranium Disposition Services to design, build and operate facilities in Paducah and Portsmouth to convert the DUF6. DOE has effectively declared DUF6 a resource in the record of decision, anticipating its conversion to non-reactive depleted uranium oxide. Making the material nonreactive is intended to eliminate the RCRA criteria that otherwise would place it in a Mixed Waste class.

Technologically Enhanced Naturally Occurring Radioactive Material

At Congress's request in 1997, the EPA arranged for the National Academy of Sciences (NAS) to study the basis for EPA's guidance on naturally occurring radioactive material. The NAS study defined technologically enhanced radioactive material (TENORM) as "any naturally occurring material not subject to regulation under the Atomic Energy Act whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities." TENORM is a byproduct of processing mineral ores containing naturally occurring radionuclides. These include uranium, phosphate, aluminum, copper, gold, silver, titanium, zircon and rare earth ores.[52] The ore beneficiation process concentrates the radionuclides above their naturally occurring concentrations. Some TENORM may be found in certain consumer products, as well as fly ash from coal-fired power plants. The most important radionuclides identified by the NAS study include the long-lived naturally occurring isotopes of radium, thorium, uranium, and their radiologically important decay products. Radium is of particular concern because it decays to form radioactive radon gas, a carcinogen contributing to lung cancer.

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[50] Oak Ridge National Laboratory, *Assessment of Preferred Depleted Uranium Disposal Forms* (ORNL/TM-2006/161) June 2000.

[51] U.S. DOE, *DUF6 Programmatic EIS*, at [http://web.ead.anl.gov/uranium/documents/nepacomp/index.cfm].

[52] U.S. EPA, TENORM Sources, at [http://www.epa.gov/radiation/tenorm/sources.htm#mining_ resources].

The NAS completed its study in 1999.[53] The EPA submitted its own report on implementing the NAS recommendations to Congress the following year along with plans to revise its TENORM guidance documents.[54] Public exposure to natural radiation resulting from ore-processing activities is subject to federal regulatory control. The NAS study noted that federal regulation of TENORM is fragmentary. Neither the EPA nor any other federal agency with responsibility for regulating radiation exposure has developed standards applicable to all exposure situations that involve naturally occurring radioactive material. Furthermore, the background radiation attributed to naturally occurring radioactive material is an important consideration in regulating TENORM, because the radionuclides being regulated as TENORM are identical to those in nature.

Uranium Mill Tailings

Uranium and thorium mill tailings are the waste byproducts of ore processed primarily for its source material (i.e., uranium or thorium) content (10 C.F.R. 40.4). The tailings contain radioactive uranium decay products and heavy metals. Mined ores are defined as source material when containing 0.05 % or more by weight of uranium or thorium (10 C.F.R. 20.1003). Byproduct material does not include underground ore bodies depleted by solution extraction. Tailings or waste produced by the extraction or concentration of uranium or thorium is defined under Section 11e.(2) of the Atomic Energy Act as amended by Title II of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA , 42 U.S.C. 7901), and is simply referred to as 11e.(2) byproduct material. UMTRCA provided for stabilization and disposal of tailings to mitigate the hazard of radon diffusion into the environment, and other hazards. Radon is a daughter-product of uranium/thorium radioactive decay.

The NRC regulates the siting and design of tailings impoundments, disposal of tailings or wastes, decommissioning of land and structures, groundwater protection standards, testing of the radon emission rate from the impoundment cover, monitoring programs, airborne effluent and offsite exposure limits, inspection of retention systems, financial surety requirements for decommissioning and long-term surveillance and control of the tailings impoundment, and eventual government ownership of pre-1978 tailings sites under an NRC general license.[55]

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[53] National Research Council Committee on Evaluation of EPA Guidelines for Exposure to Naturally Occurring Radioactive Materials, *Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials*, The National Academies Press, Washington, D.C., 1999.

[54] U.S. EPA, *Evaluation of EPA's Guidelines for Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) — Report to Congress* (EPA 402-R-00-01) June 2000.

[55] U.S. NRC, Appendix A to Part 40 — *Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for Their Source Material Content*, at [http://www.nrc.gov/reading-rm/doc-collections/cfr/part040/part040-appa.html].

Waste Disposal Policy Issues

The AEC first acknowledged the problem of waste disposal in 1955. Concerned over the hazard of radioactive waste, the AEC awarded a contract to the National Academy of Sciences to conduct research on methods to dispose of radioactive waste in geologic media and recommend disposal options within the continental limits of the United States.[56] The Academy's suggestion, at that time, was that disposal in cavities mined out in salt beds or salt domes offered the most practical and immediate solution.

In the mid-1960s, the AEC conducted engineering tests on disposing spent fuel in a salt mine near Lyons, Kansas. After developing conceptual repository designs for the mine, AEC abandoned the Lyons project in 1972 due to technical difficulties. The AEC went on to identify another site in a salt deposit and announced plans for a retrievable surface storage program as an interim measure until a repository could be developed, but the plan was later abandoned.[57]

In the 1970s, the Energy Research and Development Administration (ERDA), and later the Department of Energy (DOE), began a program of screening various geologic media for a repository (including salt deposits), and the federal sites of the Hanford Reservation and Nevada Test Site. The national problem created by accumulating spent nuclear fuel and radioactive waste prompted Congress to pass the Nuclear Waste Policy Act of 1982 (NWPA). The potential risks to public health and safety required environmentally acceptable waste disposal solutions, and the act provided for developing repositories to dispose of high-level radioactive waste and spent nuclear fuel. Under the act, the Department of Energy will assume title to any high-level radioactive waste or spent nuclear fuel accepted for a disposal in a repository constructed under the act (42 U.S.C. 10131).

In 2002, the President recommended approval of the Yucca Mountain repository site in Nevada. In a recent district court ruling, however, EPA's 10,000-year safety standard on radiation containment at the site was found to be inconsistent with the congressionally mandated recommendations of the National Academy of Sciences.[58] Depending upon successful resolution of the matter and the NRC's granting a license, the repository could begin to accept high-level waste and spent nuclear fuel in the next decade.

The controversy over DOE waste incidental to reprocessing appears to have been resolved by redefining high-level radioactive wastes as excluding the residue in high-level waste storage-tanks. However, Congress has requested the National Research Council to study DOE's plans to manage the residual tank waste and report

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[56] Committee on Waste Disposal, National Research Council, *The Disposal of Radioactive Waste on Land*, National Academies Press, Washington D.C., 1957.

[57] Commission on Geosciences, Environment and Resources, *Nuclear Wastes: Technologies for Separations and Transmutation*, National Academies Press, Washington D.C., 1996.

[58] Nuclear Energy Institute, Inc. V. Environmental Protection Agency, No. 1258 United States Court of Appeals, July 9, 2004.

on the adequacy of the plans (P.L. 108-375). The DOE also operates the Waste Isolation Pilot Plant in New Mexico to dispose of the transuranic waste generated by the weapons program. New Mexico's Governor, concerned that waste incidental to reprocessing could end up at WIPP, ordered the state's Department of Environmental Management to amend WIPP's hazardous waste permit so that only waste listed on DOE's Transuranic Waste Baseline Report is explicitly permitted for disposal at WIPP.[59]

When Congress passed the Low-Level Radioactive Waste Policy Act in 1980, three states — Nevada, South Carolina, and Washington — hosted disposal sites for commercially generated low-level waste. The act encouraged the formation of multi-state compacts in which one state would host a disposal facility for the member states. The new facilities were to begin operation in by the end of 1985. When it became clear that the deadline would not be met, Congress extended the deadline to the end of 1992 in the amended act of 1986 (P.L. 99-240). Since then, a new commercial site has been licensed in Utah, and the Nevada site has closed.

Much of the low-level waste disposed of as Class A consists of debris, rubble, and contaminated soil from decommissioning DOE and commercial nuclear facilities that contain relatively little radioactivity. These decommissioning wastes make up much larger volumes than low-level waste generated by operating nuclear facilities. The term "low-activity" has been used in describing the waste, although it lacks regulatory or statutory meaning. The National Research Council, in its interim report *Improving the Regulation and Management of Low-Level Radioactive Wastes* found that the current system of regulating low-activity waste lacked overall consistency.[60] As a consequence, waste streams having similar physical, chemical, and radiological characteristics may be regulated by different authorities and managed in disparate ways.

In an Advance Notice of Proposed Rulemaking (ANPR), the EPA proposed analyzing the feasibility of disposing of certain low-activity radioactive wastes in the RCRA Subtitle C (hazardous waste) landfills, provided that legal and regulatory issues can be resolved.[61] The NRC, in collaboration with the state of Michigan, recently permitted certain very low-activity wastes from decommissioning of the Big Rock Point nuclear power plant to be sent to a RCRA Subtitle D (solid waste) landfill, and other states have also determined that solid waste landfills offer sufficient protection for low-activity waste.[62] In a recent decision, however, the NRC rejected a staff proposal to permanently allow disposal of low-activity waste in solid

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[59] New Mexico Environmental Department, *NMED WIPP Information Page*, at [http://www.nmenv.state.nm.us/wipp/].

[60] National Research Council of the National Academies, *Improving the Regulation and Management of Low-Level Radioactive Wastes — Interim Report on Current Regulations, Inventories, and Practices*, National Academies Press, 2003.

[61] 68 Federal Register 65,120, November 18, 2003.

[62] Margaret V. Federline , U.S. NRC, *Management and Disposal Strategies for Low-Activity Waste in the U.S.*, White Paper, December 8, 2004.

waste landfills.[63] If found to be acceptable, disposing of low-activity waste at RCRA C and D landfills could alleviate the future capacity constraints at the three operating low-level waste facilities.

Radioactive waste classification continues to raises issues for policymakers. Radioactive waste generation, storage, transportation, and disposal leave little of the national geography unaffected. The weapons facilities that processed and stored radioactive waste have left a lasting and expensive environmental legacy that the DOE is attempting to remedy by accelerating the cleanup of those contaminated sites. The standards for public exposure to low-level radiation from the repository or cleanup of the weapons facilities have not been reconciled by EPA and NRC. The lower limit on what may be classified as radioactive waste is undefined, and both EPA and NRC jurisdiction overlap on disposal of this waste stream.

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[63] "NRC Surprises, Rejects Rule on Nuke Material Recycling and Disposal," *The Energy Daily*, June 6, 2005

Glossary

BWR — boiling water reactor.

curie — the basic unit describing the radioactive intensity of a material. One curie equals 37 billion (37×10^9) disintegrations/second, which is approximately the activity of 1 gram of radium.

isotope — one of several nuclides of the same element, thus the same number of protons in the nucleus (e.g. 92 for uranium) but differing in the number of neutrons, hence U-234, U-235, U-238.

microcurie — one millionth of a curie (1×10^{-6} curie); also expressed as μcurie

millicurie — one thousandth of a curie (1×10^{-3} curie); also expressed as mcurie

millirem — one-thousandth of a REM (Radiation Equivalent Man). It is the term for the conventional unit of ionizing radiation dose (rad) equivalent used for radiation protection purposes.

MTHM — metric ton of heavy metal. 1000 kilograms (the U.S. equivalent of 2,200 lbs) of original uranium in fuel, excluding cladding and assembly hardware.

nanocurie — one billionth of a curie (1×10^{-9} curie); also expressed as ηcurie.

picocurie — one trillionth curie (1×10^{-12} curie); also expressed as pcurie.

PWR — pressurized water reactor.

Transuranic elements — neptunium, plutonium, americium, and curium.

Appendix

Table A-1. Uranium Mill Tailing Site Volume and Activity

Site	Disposal Cell Waste Volume		Disposal Cell Radioactivity		Tailings Activity
	Million Cubic Yards	Million Cubic Meters	Total Curies (^{226}Ra)	Average Curies/ Cu. mtr.	Average Curies/gram (^{226}Ra)
Maybell Mill Site, CO	3.50	4.58	445	0.00009	0.000000000
Mexican Hat Mill Site, UT	3.48	4.55	1,800	0.00009	0.000000000
Edgemont Mill Site, SD	3.00	3.92	527	0.00013	NA
Falls City Mill Site, TX	5.80	7.59	1,277	0.00016	0.000000000
Ambrosia Lake Mill Site,	5.20	6.80	1,850	0.00027	0.000000000
Durango Mill Site, CO	2.53	3.31	1,400	0.00045	0.000000000
Rifle Mills (Old & New)	3.76	4.92	2,738	0.00055	0.000000000
Salt Lake City Mill Site, UT	2.80	3.66	1,550	0.00074	0.000000000

Source: U.S. DOE Energy Information Administration; "Remediation of UMTRCA Title I Uranium Mill Sites Under the UMTRA Project Summary Table: Uranium Ore Processed, Disposal Cell Material, and Cost for Remediation as of December 31, 1999," at [http://www.eia.doe.gov/cneaf/nuclear/page/umtra/title1sum.html]

Notes:

Total Curies and Average Curies expressed as Radium-226 equivalence.

1 cubic meter = 1.308 cubic yards

Table A-2. Low-Level Waste Commercial Disposal Site Volume and Activity

Site	Cubic Feet	Cubic Meter	Activity Curies	Curies/ cubic-meter
Barnwell, SC	788,000	22,316	443,600	19.88
Richland,	295,300	8,363	92,980	11.12
Beatty, NV	59,480	1,684	11,320	6.72
1 ft^3 = 0.02832 m^3				

Source: U.S. DOE, Table 1. Commercial Gross Volume and Activity Distribution in *Disposal of Low-Level and Mixed Low-Level Radioactive Waste During 1990 (DOE/EH-0332p)*, August 1993.

Table A-3. Spent Fuel Specific Activity

	Fuel Rod Type					
	BWR [1]	PWR [2]	PWR [3]	PWR [4]	PWR [5]	PWR [6]
Fuel Rod array	8x8	17x17	17x17	17x17	17x17	17x17
GW/d/MTHM	40	50	20	20	50	50
U-236 enrichment (%)	3.5	4.3	3	3	4.5	4.5
Decay time (years)	14	15	10	100	10	100
Activity / assembly (curies)	229594	68273	150000	20000	450000	40000
Nom vol/ assembly (cu. m)[7]	0.086	0.19	0.19	0.19	0.19	0.19
Calculated curies/ cu. m	2669698	359332	789000	105000	2370000	211000

Source:
[1] Boiling Water Reactor, Appendix A, Table A-13, Yucca Mt. EIS
[2] Pressurized Water Reactor, Appendix A, Table A-12, Yucca Mt. EIS
[3] Pressurized Water Reactor, Appendix C, P 82, Oak Ridge National Laboratory "Investigation of Nuclide Importance to Functional Requirements Related to Transport and Long-Term Storage of LWR Spent Fuel (ORNL/TM/12742), 1995.
[4] Appendix C, P 82, ORNL/TM/12742.
[5] Appendix C, P 85, ORNL/TM12742.
[6] Appendix C, P 85, ORNL/TM12742.
[7]Table A-18, Reference Characteristics for Average Commercial Spent Fuel Assemblies, Appendix A, Inventory of Characteristics of Spent Nuclear fuel, High-Level Radioactive Waste, and Other Materials, Yucca Mountain EIS.

Notes:
A typical fuel rod used in commercial nuclear power reactors consists of uranium dioxide pellets surrounded by zirconium alloy cladding. The uranium oxide pellets consist of 3-4% fissionable uranium-235, and a balance of nonfissionable U-238. An individual fuel assembly consists of arrays of fuel rods. The Energy Information Administration (EIA) notes 131 reactor fuel assembly types on its Nuclear Fuel Data Survey Form RW-859 (OMB No. 1901-0287). The assemblies range in weight from ~70 kilograms uranium for a Humboldt Bay Assembly Class (boiling water reactor) to ~ 464 kilograms uranium for a Babcock & Wilcox 15 x 15 Assembly Class (pressurized water reactor). During the sustained chain reaction in an operating reactor, the U-235 splits into highly radioactive fission products, while the U-238 is partially converted to plutonium-239 by neutron capture, some of which also fissions. Further neutron capture creates other transuranic elements.

Figure A-1. 10 CFR 61.55 Table 1

TABLE 1

Radionuclide	Concentration curies per cubic meter
C–14	8
C–14 in activated metal	80
Ni–59 in activated metal	220
Nb–94 in activated metal	0.2
Tc–99	3
I–129	0.08
Alpha emitting transuranic nuclides with half-life greater than 5 years	[1] 100
Pu–241	[1] 3,500
Cm–242	[1] 20,000

[1] Units are nanocuries per gram.

Figure A-2. 10 CFR 61.55 Table 2

TABLE 2

Radionuclide	Concentration, curies per cubic meter		
	Col. 1	Col. 2	Col. 3
Total of all nuclides with less than 5 year half-life	700	(1)	(1)
H–3	40	(1)	(1)
Co–60	700	(1)	(1)
Ni–63	3.5	70	700
Ni–63 in activated metal	35	700	7000
Sr–90	0.04	150	7000
Cs–137	1	44	4600

[1] There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 2 determine the waste to be Class C independent of these nuclides.