6. ENVIRONMENTAL RESTORATION WASTES

6.1 INTRODUCTION

The fundamental goal of the Department of Energy's Office of Environmental Restoration is to ensure that risks to the environment and to human health and safety posed by inactive and surplus facilities and sites contaminated by radioactive, hazardous, or mixed wastes are either eliminated or reduced to prescribed, safe levels. The main objective is to clean up the current waste inventory within the DOE nuclear complex by the year 2019. Although encompassing all requirements prescribed by applicable federal, state, and local environmental statutes and regulatory requirements, this goal is not limited to regulatory compliance. Protection of human health and safety and the environment is DOE's paramount concern.

Environmental restoration efforts are proceeding in two major areas: remedial action (RA) and decontamination and decommissioning (D&D) activities. RA and D&D activities include cleanup of facilities and areas that supported defense-related activities, such as nuclear weapon component fabrication, and nondefense, civilian nuclear power activities, such as the development of heat sources for the space program and the operation of small test reactors. These activities include the Uranium Mill Tailings Remedial Action Program (UMTRAP), the Formerly Utilized Sites Remedial Action Program (FUSRAP), and other environmental restoration activities associated with DOE Field Offices throughout the country. Only D&D activities at facilities transferred to the Office of Environmental Restoration and Waste Management (EM) are discussed.

The map in Fig. 6.1 locates the DOE offices responsible for environmental restoration activities. The distribution by waste class of the estimated volume of waste to be generated by the environmental restoration activities is shown in Fig. 6.2. Additional details on UMTRAP sites and FUSRAP sites are identified in Fig. 6.3 and Fig. 6.4, respectively. The total volume of waste associated with UMTRAP is shown in Fig. 6.5, and the total volume of FUSRAP waste is shown in Fig. 6.6.

The estimated total volumes of waste from DOE environmental restoration activities are summarized in Table 6.1. Waste inventories from completed environmental restoration activities are indicated as being in either permanent or interim storage. Projected additional waste volumes from future environmental restoration activities are reported as estimated remaining inventories.

6.2 THE OFFICE OF ENVIRONMENTAL RESTORATION

The Office of Environmental Restoration (EM-40) has responsibility for RA and D&D activities within EM.[1] RA activities involve the assessment and cleanup of inactive DOE sites and deal primarily with contaminated environmental media such as soil and groundwater. D&D activities entail the safe caretaking of surplus nuclear facilities and their complete dismantling and removal, or in-place stabilization and isolation. As shown in Fig. 6.1, RA and D&D activities are managed under 17 projects through 9 DOE Field Offices and 1 DOE project office: Albuquerque, Chicago, Fernald, Idaho, Nevada, Oak Ridge, Richland, Rocky Flats, Savannah River, and San Francisco. UMTRAP, authorized by Congress in 1978, and FUSRAP, authorized by DOE in 1974, are 2 of the 17 projects.

6.2.1 Activities

The RA and D&D activities under the auspices of EM-40 were formerly supported under the DOE Offices of Defense Programs, Energy Research, and Nuclear Energy.

6.2.1.1 Remedial action

RA activities entail site discovery, preliminary assessment, and inspection; site characterization, analysis of cleanup alternatives, and selection of remedy; cleanup and site closure; and site compliance monitoring. Although such activities may deal with tanks, buildings, or structures, most are concerned with contaminated environmental media such as soil and groundwater.

The principal regulatory requirements for RA activities are derived from the Resource Conservation and Recovery Act (RCRA);[2] the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);[3] and the National Environmental Policy Act (NEPA).[4]

RA activities may further be subject to important regulatory requirements imposed by the states. Other requirements are set forth in various DOE Orders and standards and other guidance documents.[1]

6.2.1.2 Decontamination and decommissioning

D&D activities emphasize the safe caretaking of surplus nuclear facilities and their decontamination for dismantlement and removal. They include surveillance and maintenance, assessment and characterization, environmental review, engineering, D&D operation, and project closeout. Most D&D activities are performed on facilities such as reactors, hot cells, processing plants, storage tanks, and other structures from which, in general, there have been no known releases. There are approximately 500 contaminated facilities currently included in the EM-40 inventory for D&D. The objectives of D&D activities are to decontaminate these facilities and to eliminate any potential hazards to public health and the environment.

D&D activities are carried out in accordance with the provisions prescribed in NEPA and the Atomic Energy Act (AEA)[5] and with requirements set forth in various DOE Orders and standards and other guidance documents. In addition, the provisions of CERCLA and RCRA may also apply to those facilities from which there has been a release or from which there is a potential release. State requirements may apply in certain instances.

6.2.2 Programs

Environmental restoration activities under the auspices of the Office of Environmental Restoration are managed by three offices: Southwestern Area Programs, Northwestern Area Programs, and Eastern Area Programs. Each office manages both RA and D&D activities.

The projected remaining volumes of radioactive waste that will result from environmental restoration activities are listed by program in Tables 6.2 through 6.7. The wastes include low-level, mixed, transuranic, and other radioactive materials. The estimated volumes of radioactive soils and radioactive solid waste resulting from the environmental restoration activities are reported in Tables 6.2 and 6.3, respectively.

6.2.2.1 Southwestern Area Programs

Southwestern Area Programs include all EM-40 activities conducted out of the DOE Nevada Field Office, Albuquerque Field Office, and Rocky Flats Site Office.

At the DOE Nevada Field Office, the environmental restoration program includes conducting D&D, characterization, remedial design, and remedial actions for 11 subprojects at the Nevada Test Site (NTS) and at off-site areas where nuclear tests have been conducted. Off-site locations include: Amchitka Island, Alaska; the Rio Blanco and Rulison Gas Stimulation sites in Colorado; the Gasbuggy Gas Stimulation and Gnome Coach sites in New Mexico; and the Tatum Dome Site in Mississippi. The EM-40 activities at NTS involve cleanup of areas of contamination from aboveground and underground nuclear weapons testing. The main contaminants include radionuclides, organic compounds, metals, hydrocarbons, and various residues used during test boring, drilling, and instrumentation.

DOE Albuquerque Field Office operations are managed as five separate projects. There are more than 2,500 potential RA sites under the auspices of the Albuquerque Field Office and more than 20 surplus facilities identified for D&D. The main contaminants include radionuclides, solvents, gasoline, organics, metals, high-explosive residues, and uranium mill tailings.

Albuquerque Laboratories activities take place at the South Valley Superfund Site, the Inhalation Toxicology Research Institute, Sandia National Laboratories, and Los Alamos National Laboratory (LANL). D&D is currently being conducted on a separator pit at LANL. Albuquerque Production environmental restoration activities include RA at the Pantex, Kansas City, Pinellas, and Mound plants. D&D is currently under way at the special metallurgical building at the Mound Plant. There are ongoing site assessments, Remedial Investigations/Feasibility Studies (RI/FS), and remedial design and remedial action activities for lagoons, waste ponds, landfills, disposal areas, firing sites, underground storage tanks, and other structures.

The Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604) authorized DOE to undertake the stabilization and control of uranium mill tailings in a safe and environmentally sound manner and, where appropriate and practical, to reprocess existing tailings to extract residual uranium and other mineral values. The Act also specifies RA, as required, on properties in the vicinity of the tailings sites.[6] Initial tasks under UMTRAP were to (1) designate inactive uranium mill tailings sites for RA and (2) evaluate the economic viability of reprocessing tailings. Currently, two Albuquerque projects oversee work for UMTRAP surface and groundwater assessment and cleanup.

Twenty-five inactive uranium processing sites and associated vicinity properties located in ten states and four Indian reservations, and the vicinity properties associated with the Edgemont, South Dakota, inactive uranium mill, currently owned by the Tennessee Valley Authority (TVA), are presently included in UMTRAP. All of the sites are located in the western United States except for one site in Canonsburg, Pennsylvania. Engineering assessment and economic evaluation documents about each site have been published.

During FY 1991, the UMTRAP achieved the following major accomplishments:

- Completed remedial actions at the Lowman, Idaho, processing site.
- Completed 43% of the Phase II remedial actions at Grand Junction, Colorado.
- Completed remedial actions on 332 vicinity properties; certified 446 vicinity properties; initiated contracts covering remedial actions on 233 vicinity properties; and completed vicinity property activities at the Lowman, Idaho, UMTRAP site.

Table 6.4 gives the current RA status, duration schedules, and estimated total waste volume for the 25 UMTRAP sites.[7,8] At the end of 1991, over 10.6 million cubic meters of mill tailings and other (subordinate) wastes, reported in this document as 11e(2) by-product material, had been stabilized at 11 sites where site remedial action activities were completed. The subordinate wastes include soils contaminated by windblown tailings, ore in storage areas, material underlying tailings piles, and contaminated soils from vicinity properties. It should be noted that quantities of subordinate wastes typically increase as RA work commences and efforts are made to ensure the adequacy of the cleanup procedures.

The uranium mill tailings at the UMTRAP sites have a low specific activity that is the result of naturally occurring radioactive elements. Depending on specific site characteristics, these tailings may be stabilized on-site or removed to other locations and stabilized. The criteria used in UMTRAP site cleanup and waste disposal work are based on EPA standards[9] that became effective in March 1983. As shown in Table 6.4, UMTRAP remedial activities are scheduled to be completed by June 1995; however, certification and licensing activities will not be completed until September 1998.

The projected volumes of wastes from uncompleted UMTRAP sites are given in Table 6.5. Also given in this table is the estimated concentration of ^{226}Ra associated with the waste at their sites which has been determined from representative samples obtained from these sites.

The Grand Junction Projects Office and Monticello RA Projects are also managed out of the Albuquerque Field Office. There are ongoing RA activities for surface and groundwater cleanup at the Monticello Mill Tailings Site in Utah and at the Grand Junction Projects Office Site in Colorado.

The Rocky Flats Plant is a nuclear weapons manufacturing facility. The EM-40 activities there are responsible for the site assessments, RI/FS, and RA for 178 sites contaminated from earlier waste storage and disposal. Storage and disposal of hazardous, radioactive, and mixed wastes occurred on-site in the past. Off-site locations include three reservoirs and one land area; these areas may have received contaminated effluent and sediments originating from the Plant. Rocky Flats is also tasked to design, procure, construct, operate, and maintain decontamination facilities for waste generated by EM-40 activities.

6.2.2.2 Northwestern Area Programs

Northwestern Area Programs encompass all EM-40 activities that are managed through the DOE Idaho, Richland, and San Francisco Field Offices. These activities are located on both DOE and contractor-owned sites and facilities located in Idaho, Washington, and California.

The Idaho National Engineering Laboratory (INEL) was established in 1949 as a site where nuclear reactors, support facilities, and equipment could be safely built, tested, and operated — primarily to prove that the atom could be used safely to generate electric power. Today, INEL is one of DOE's principal centers for conducting nuclear energy research and development. Previous activities have resulted in the generation of high-level, low-level, transuranic, and mixed wastes, as well as acids, solvents, asbestos, and heavy metals. There is contamination of structures, groundwater, and surface water within the site. The EM-40 program consists of the remediation of 8 waste area groups containing about 370 waste release sites at burial grounds, ponds, reactor areas, landfills, and underground storage tanks; and the D&D of 15 areas including reactors, tanks, laundry, and other facilities.

DOE activities at the Hanford Site, under the direction of the DOE Richland Field Office, have been producing nuclear fuel and materials since the early 1940s. The wastes at Hanford include radioactive materials, hazardous chemicals, and mixed wastes primarily from the production and chemical processing of plutonium for defense purposes, but also from nuclear fuel research and fabrication activities. About 1,100 waste sites have been identified, most having resulted from on-site storage or soil column disposal of low-level, hazardous, and mixed wastes. More than 100 surplus facilities are contaminated with radioactivity and are scheduled for D&D. These facilities include nine former production reactors, chemical process buildings, structures, and ancillary structures. As part of the remediation of the site, the EM-40 project at Hanford is responsible for the construction of a disposal facility to receive cleanup wastes and the closure of underground storage tanks and other RCRA closures.

The mission of the DOE San Francisco Field Office has been nuclear weapons research, as well as nuclear and other energy research. The wastes generated include transuranic, low-level, hazardous, and mixed wastes; contaminants include a wide variety of radionuclides, polychlorinated biphenyls (PCBs), volatile organic compounds, and metals. The San Francisco Field Office installations where EM-40 has program activities include Lawrence Livermore National Laboratory (LLNL), Lawrence Berkeley Laboratory (LBL), Stanford Linear Accelerator Center (SLAC), General Atomics Facility, Laboratory for Energy-Related Health Research (LEHR), General Electric Vallecitos Nuclear Center, and the DOE portion of Santa Susana Field Laboratory (SSFL), known as the Energy Technology Engineering Center (ETEC).

LLNL consists of two sites: the Main Site and Site 300. Past operations at the Main Site involved the handling and storage of hazardous materials by both DOE and the former site owner, the Department of Defense, and have resulted in the release and subsequent migration of contaminants into soil and groundwater. Chlorinated hydrocarbons are dissolved in groundwater at concentrations as high as 10 ppm. The groundwater is being remediated by pumping and treating within the area of the contaminated plume. The LLNL Site 300 (about 15 miles east of the LLNL Main Site, near Tracy, California) consists of nonnuclear explosive test facilities. Past operations at Site 300 involved processing, testing, and deactivating high-explosive materials and have resulted in soil and groundwater contamination at the facility. There are several small plumes of chlorinated hydrocarbons and two plumes of tritium in the groundwater emanating from on-site pits, landfills, and debris piles. Two of the largest pits have been capped, and an interim groundwater treatment facility is extracting and treating trichloroethylene-contaminated groundwater at one of the debris piles.

The LBL site is leased to DOE by the University of California. A wide range of energy-related areas, such as particle accelerators and chemical and biomedical research, is carried out in laboratories and supporting facilities at LBL. The current EM-40 program involves the systematic assessment of soil and groundwater at the site to determine the existence and nature of any contamination prior to characterization and eventual cleanup.

The SLAC is operated by Stanford University under contract to DOE. SLAC was established in 1962 as an energy research facility dedicated to research and development of new techniques for high-energy accelerators and experimental apparatus. Past waste management practices and facility operations have resulted in PCB contamination of soils and volatile organic compound contamination of groundwater.

The DOE-owned LEHR occupies a site leased from the University of California at Davis (UCD). UCD used the laboratory for more than 30 years to conduct a DOE-sponsored research program on the health effects of exposure to low-level radiation. The research contaminated five buildings, outdoor dog pens and cages, and a tank trailer with low-level radioactive wastes and generated radioactive sludge wastes and contaminated soils in trenches and pits. Some chemical and radioactive contaminants have reached groundwater.

The ETEC portion of the SSFL consists of facilities that are used to test systems and components for use in energy, power conversion, and liquid metal development programs. Ongoing site characterization includes assessments of radioactive contaminants as well as chemical pollutants in surface water, groundwater, soil, biota, and air.

6.2.2.3 Eastern Area Programs

EM-40 activities in the Eastern Area are managed out of the DOE Oak Ridge, Fernald, Chicago, and Savannah River Field Offices. The Oak Ridge Field Office oversees EM-40 activities at Oak Ridge National Laboratory, the K-25 Site, and the Y-12 Plant on the Oak Ridge Reservation in Tennessee; the Portsmouth Gaseous Diffusion Plant, in Piketon, Ohio; and the Paducah Gaseous Diffusion Plant, in Paducah, Kentucky. DOE Defense Programs activities have generated various types of radioactive and hazardous wastes: low-level radioactive material (primarily uranium), organic solvents, corrosive waste, PCBs, heavy metals, and mixed waste. Contamination resulting from earlier waste management practices has affected groundwater, soils, surface waters, buildings, structures, and equipment. EM-40 work out of Oak Ridge includes cleanup of the K-25 Site (specifically, RA activities for the K-25 main and process plants and waste storage locations) and RA of facilities at the Y-12 Plant.

The Weldon Spring Site Remedial Action Project (WSSRAP) is also managed by the DOE Oak Ridge Field Office. WSSRAP activities include the D&D of the chemical plant processing buildings; the RA of the raffinate pits and the quarry; the restoration of contaminated vicinity properties; construction and operation of two water treatment plants and waste processing facilities; and disposal of all waste generated by site cleanup activities.

FUSRAP is primarily concerned with the cleanup of waste at sites that were formerly used to support the activities of the Manhattan Engineer District (MED), established for the Manhattan Project, and the Atomic Energy Commission (AEC). In the 1940s and 1950s, private firms and institutions were contracted by the federal government to develop processes and perform research on radioactive materials. Often the storage and processing of uranium and thorium ores, concentrates, and residues were involved. Although these sites were cleaned up to formerly acceptable levels, FUSRAP was established in 1974 to identify, re-evaluate, and, if necessary, remediate these sites. Currently, 33 sites have been identified in 13 states. Approximately one-half of these sites are in the northeastern part of the country.

RA activities for FUSRAP are ongoing at sites that include residential properties, municipal landfills, open fields, abandoned industrial plants, and operating industrial and commercial facilities. To date, RA on 171 of the designated 311 FUSRAP vicinity properties has been completed. Initial RA activities have been completed at 10 of the 33 sites and partially completed at 12 additional sites, as shown in Table 6.6.[10] Table 6.7 gives the estimated volumes of waste from FUSRAP activities remaining to be completed; only waste with low concentrations of radioactivity is anticipated. The total

volume of radioactive waste is expected to be about 1,600,000 m^3, including waste that has already been placed in storage. Most of this waste will be classified as 11e(2) by-product material. Site radiological surveys have developed considerable detailed information, and comprehensive site-by-site data have been compiled.

The DOE Fernald Field Office has responsibility for environmental restoration of the Fernald Environmental Management Project (FEMP). FEMP, formerly the Feed Materials Production Center, had the mission to produce feed materials for nuclear reactor fuel as a part of the nation's defense program. At FEMP, the main contaminants include residues containing uranium and radium, wastewaters and various solid waste contaminated with uranium and thorium materials, reactive chemicals, oils contaminated with uranium, and organic solvents. A site-wide RI/FS was initiated in 1986 to formulate, assess, and recommend RA alternatives. The FEMP program also includes the Reactive Metals, Inc. (RMI) Extrusion Plant, which has on-site and off-site surface soil and groundwater uranium contamination, and the adjacent Fields Brook site, which has contamination from PCBs, chlorinated solvents, toxic metals, and trichloroethylene. Currently, RA is ongoing for waste ponds, landfills, disposal areas, silos, surface water, and groundwater. D&D is being conducted for production area structures, equipment, and stockpiles. Waste management activities for the characterization, storage, treatment, disposal, and minimization of currently generated or backlog waste are also ongoing.

The DOE Chicago Field Office oversees two EM-40 activities, Chicago and Battelle Columbus Laboratories. The primary mission at Chicago is energy research, development, and demonstration. Waste types include transuranic, low-level, hazardous, and mixed wastes. Chicago projects involve six sites: Argonne National Laboratory-East, Illinois; Argonne National Laboratory-West, Idaho; Brookhaven National Laboratory, New York; Fermi National Accelerator Laboratory, Illinois; Princeton Plasma Physics Laboratory, New Jersey; and Ames Laboratory, Iowa. Activities include D&D of two retired nuclear reactors and RA for soil and groundwater contamination, disposal sites, underground storage tanks, and PCB cleanup.

The Battelle Columbus Laboratory Decommissioning Project (BCLDP) in Ohio includes the D&D of 15 contaminated buildings and surrounding soils which have been used for government-sponsored nuclear research.

The DOE Savannah River Field Office manages the EM-40 activities at the Savannah River Site in South Carolina. Its historical mission of producing nuclear materials for defense programs has resulted in the generation of waste by-products including liquid high-level, solid transuranic, low-level, hazardous, and mixed wastes. Soil and groundwater contamination has resulted from contaminants migrating from seepage and settling basins, unlined disposal pits, waste piles, burial grounds, and underground storage tanks. D&D activities are currently under way at the Heavy Water Components Test Reactor and two other facilities. RA activities are ongoing for burial grounds, tanks, pits, basins, and other groundwater areas.

6.3 REFERENCES

1. U.S. Department of Energy, Environmental Restoration and Waste Management Five-Year Plan — Fiscal Years 1994–1998, Vols. 1 and 2, Washington, D.C. (December 1992).

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3. U.S. Congress, Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Pub. L. 96-510, Dec. 1980, as amended.

4. U.S. Congress, National Environmental Policy Act of 1969, Pub. L. 91-190, Jan. 1, 1970.

5. U.S. Congress, Atomic Energy Act of 1954, Pub. L. 83-703, Aug. 1954, as amended.

6. U.S. Nuclear Regulatory Commission, "Standards for Cleanups of Land and Buildings Contaminated with Residential Radioactive Materials from Inactive Uranium Processing Sites," Code of Federal Regulations, 40 CFR Part 192, Sect. 10 (July 1, 1987).

7. Frank Bosiljevac, U.S. Department of Energy, Uranium Mill Tailings Project Office, Albuquerque, New Mexico, memo to Marilyn Tolbert-Smith, Computer Specialist, EM-433, Headquarters, "Update of the Integrated Data Base Report," dated Feb. 27, 1992.

8. Mark Minteer, Jacobs Engineering Group, Inc., Albuquerque Operations, letter to Marilyn Tolbert-Smith, U.S. Department of Energy, Headquarters, EM-433, dated Sept. 17, 1992.

9. U.S. Environmental Protection Agency, Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192), EPA 520/4-82-013-1 and EPA 520/4-82-013-2, Washington, D.C. (October 1982).

10. Lester K. Price, U.S. Department of Energy, DOE Field Office, Oak Ridge, Tennessee, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of Formerly Utilized Sites Remedial Action Data in the Integrated Data Base Report," dated Mar. 24, 1992.

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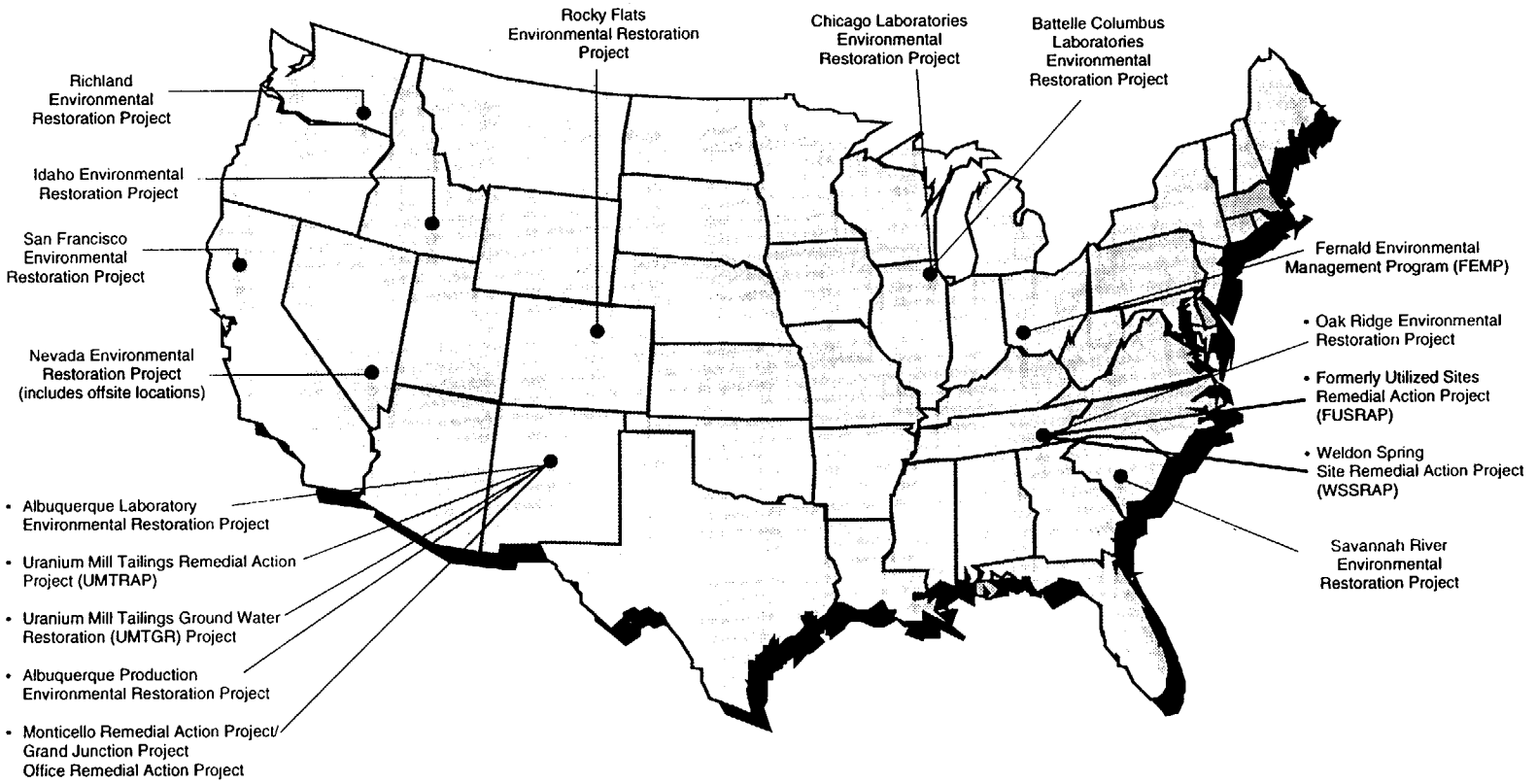


Fig. 6.1. Locations of 17 project offices for DOE environmental restoration activities.

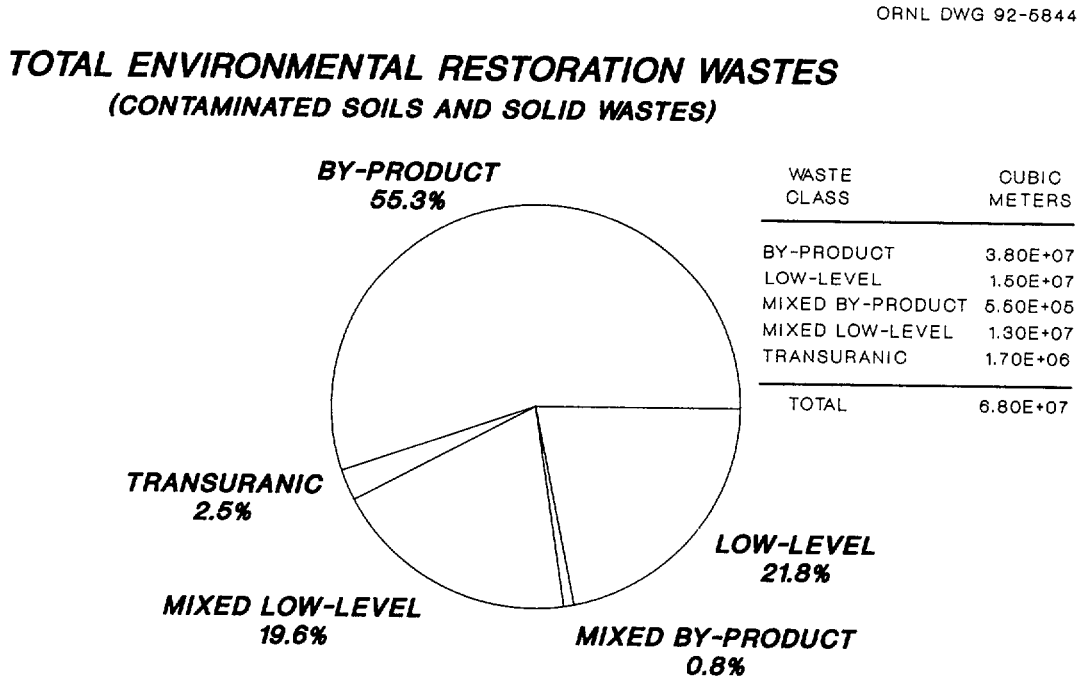
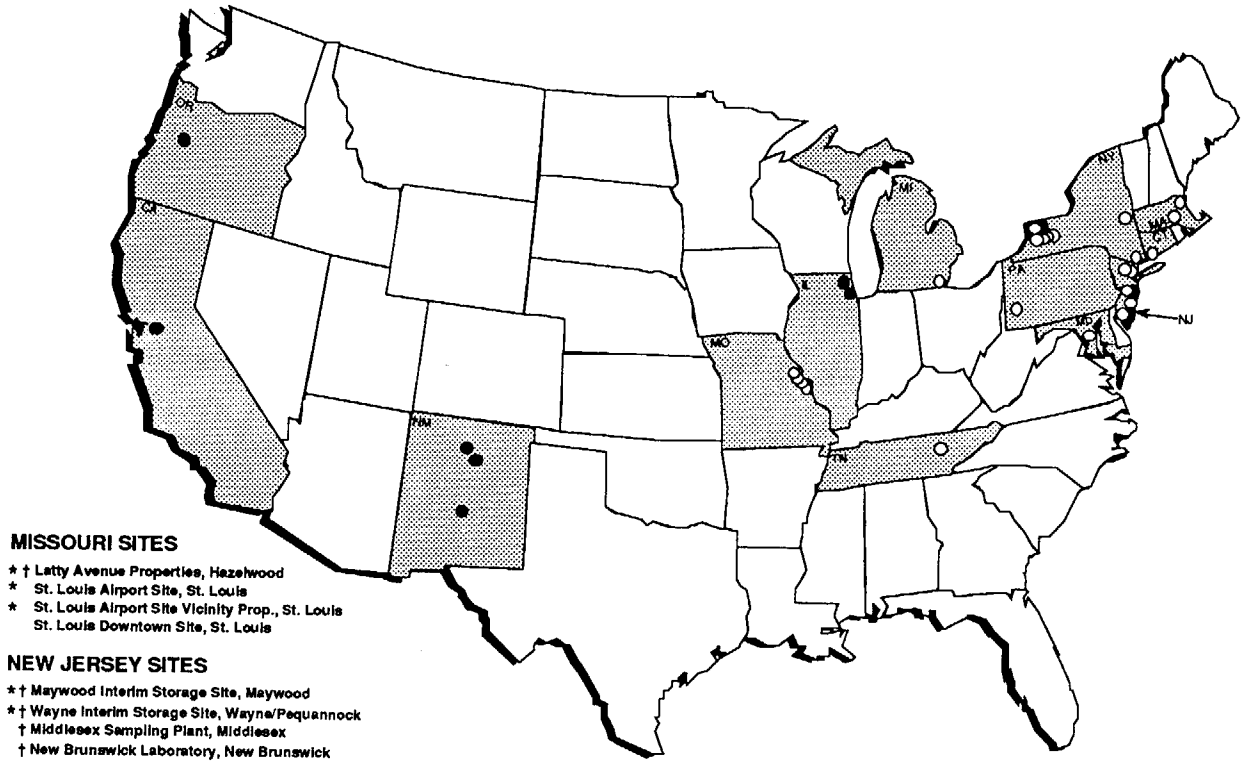


Fig. 6.2. Estimated total volumes of different classes of wastes from environmental restoration activities.

1 CANONSBURG, PA•
2 DURANGO, CO•
3 GRAND JUNCTION, CO
4 GUNNISON, CO
5 NEW RIFLE, CO
6 OLD RIFLE, CO
7 NATURITA, CO
8 MAYBELL, CO
9 SLICK ROCK (NC), CO••
10 SLICK ROCK (UC), CO•••
11 RIVERTON, WY•
12 CONVERSE CO., WY•
13 BELFIELD, ND
14 BOWMAN, ND
15 FALLS CITY, TX
16 SHIPROCK, NM•
17 AMBROSIA LAKE, NM
18 TUBA CITY, AZ•
19 MONUMENT VALLEY, AZ
20 SALT LAKE CITY, UT•
21 GREEN RIVER, UT•
22 MEXICAN HAT, UT
23 LOWMAN, ID•
24 LAKEVIEW, OR•
25 EDGEMONT, SD•

• SITE WORK COMPLETED
•• NORTH CONTINENT SITE
••• UNION CARBIDE SITE

Fig. 6.3. Locations of UMTRAP sites.



MISSOURI SITES

* † Latty Avenue Properties, Hazelwood
* St. Louis Airport Site, St. Louis
* St. Louis Airport Site Vicinity Prop., St. Louis
St. Louis Downtown Site, St. Louis

NEW JERSEY SITES

* † Maywood Interim Storage Site, Maywood
* † Wayne Interim Storage Site, Wayne/Pequannock
† Middlesex Sampling Plant, Middlesex
† New Brunswick Laboratory, New Brunswick
Du Pont & Company, Deepwater

NEW YORK SITES

† Niagara Falls Storage Site, Lewiston
† Colonie Interim Storage Site, Colonie
Ashland 1, Tonawanda
Ashland 2, Tonawanda
Linde Center, Tonawanda
Seaway Industrial Park, Tonawanda
Baker and Williams Warehouses, New York City

ADDITIONAL SITES

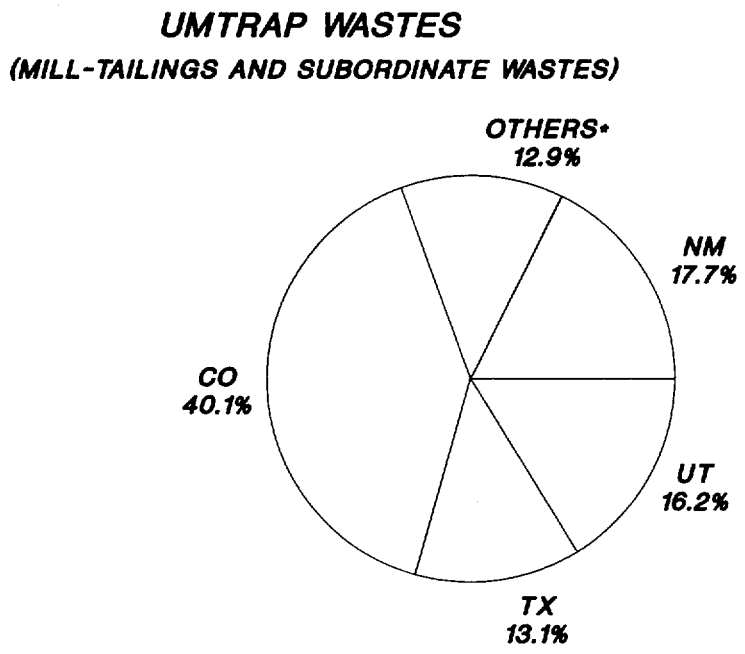
Aliquippa Forge, Aliquippa, PA
Elza Gate Site, Oak Ridge, TN
General Motors, Adrian, MI
Seymour Specialty Wire, Seymour, CT
* Shpack Landfill, Norton, MA
Ventron Corporation, Beverly, MA
W.R. Grace & Company, Curtis Bay, MD

COMPLETED SITES

Acid/Pueblo Canyon, Los Alamos, NM
Albany Research Center, Albany, OR
Bayo Canyon, Los Alamos, NM
Chupadera Mesa, White Sands Missile Range, NM
Kellex/Pierpont, Jersey City, NJ
Middlesex Municipal Landfill, Middlesex, NJ
National Guard Armory, Chicago, IL
Niagara Falls Storage Site Vicinity Prop., Lewiston, NY
University of California, Berkeley, CA
University of Chicago, Chicago, IL

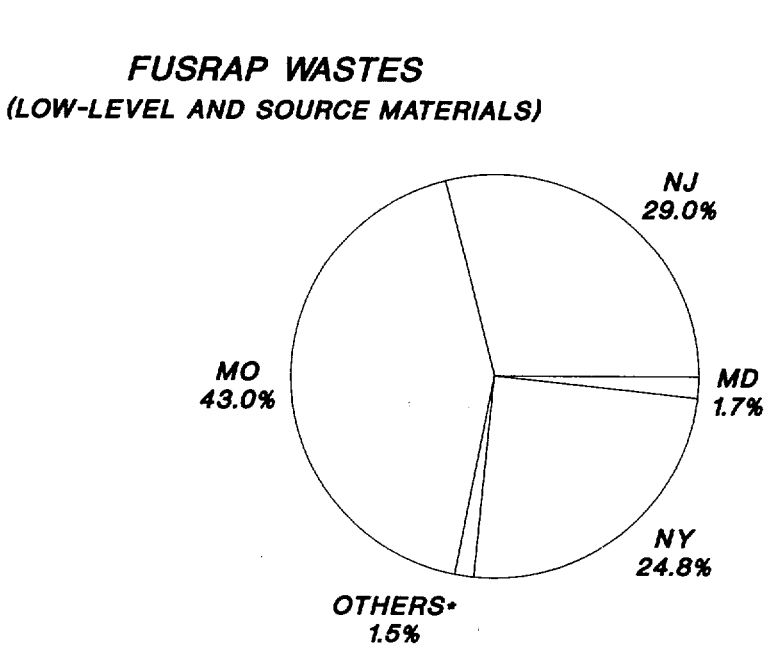
O REMEDIAL ACTION ONGOING OR PLANNED
● REMEDIAL ACTION COMPLETED
† DOE-OWNED OR -LEASED SITE
★ NPL SITE
STATE WITH FUSRAP SITE(S)

Fig. 6.4. Locations of FUSRAP sites.



STATE	CUBIC METERS
AZ*	1.26E+06
CO	1.28E+07
ID*	1.01E+05
ND*	1.21E+05
NM	5.64E+06
OR*	7.31E+05
PA*	2.26E+05
SD*	3.44E+04
TX	4.17E+06
UT	5.16E+06
WY*	1.67E+06
TOTAL	3.19E+07

Fig. 6.5. Estimated total volumes of wastes from UMTRAP activities in various states.



STATE	CUBIC METERS
CA*	2.30E+01
CT*	1.90E+01
IL*	5.00E+01
MA*	1.25E+04
MD	2.75E+04
MI*	1.53E+02
MO	6.85E+05
NJ	4.63E+05
NM*	1.46E+03
NY	3.95E+05
OR*	2.73E+03
PA*	2.90E+01
TN*	6.80E+03
TOTAL	1.59E+06

Fig. 6.6. Estimated total volumes of wastes from FUSRAP activities in various states.

Table 6.1. Summary of current and projected waste volumes from environmental restoration activities

Program	Waste volume, 10^3 m^3		
	TRU[a]	LLW[a]	By-product material[a,b]
A. Permanent storage[c]			
UMTRAP			11,000[d]
FUSRAP			11[e]
GJRAP			52[f]
Total			11,000
B. Interim storage			
FUSRAP			330[e]
C. Estimated remaining inventory[g]			
ER soils[h]	1,700	27,000	27,000
ER solids[i]	5.6	1,400	660
Total	1,700	28,000	28,000

[a]Volume estimates include quantities determined or projected to be mixed wastes. All values are given to two significant figures.

[b]By-product material is defined in Section 11e(2) of the Atomic Energy Act of 1954 (P.L. 83-703) as the tailings or waste products produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.

[c]Volumes in permanent storage as of December 31, 1991.

[d]Includes uranium mill tailings and all contaminated material outside the immediate tailings pile. Once the cover is placed, all permanently stored material is considered to be tailings.

[e]Includes LLW and source material.

[f]GJRAP completed in 1988.

[g]Detailed waste projections for environmental restoration activities, for UMTRAP, and for FUSRAP are given in Tables 6.2 and 6.3, in Tables 6.4 and 6.5, and in Tables 6.6 and 6.7, respectively.

[h]Radioactively contaminated soils from environmental restoration activities.

[i]Radioactively contaminated solid wastes from environmental restoration activities.

Table 6.2. Estimated volumes of radioactive soils from environmental restoration activities[a,b]

ER Programs	Waste volume, m^3					
	LLW	Mixed LLW	By-product[c]	Mixed by-product[c]	TRU[d]	Total
Southwestern Programs						
Nevada Field Office	3,200,000	1,600,000			1,600,000	6,400,000
Albuquerque Labs	510					510
Albuquerque Production	200,000	220,000				420,000
UMTRA (UMTRAP)			32,000,000			32,000,000
Grand Junction Projects Office			1,800,000			1,800,000
Rocky Flats Plant (RFP)[e]						
Northwestern Programs						
Richland Field Office	9,000,000	11,000,000				20,000,000
San Francisco Field Office	1,000	110			64,000	65,000
Idaho Field Office	48,000	13,000			28,000	89,000
Eastern Programs						
Oak Ridge Field Office	10,000	340,000			360	350,000
Weldon Spring (WSSRAP)			220,000			220,000
FUSRAP	66,000	28,000	1,500,000			1,600,000
Fernald (FEMP)	690,000		1,200,000	540,000		2,400,000
Chicago Field Office	29,000	17,000		120	360	47,000
Battelle Columbus Labs (BCLDP)	170				10	180
Savannah River Field Office	350,000	210,000		2,600	290	560,000
Total	14,000,000	13,000,000	37,000,000	540,000	1,700,000	66,000,000

[a]Estimated as of December 31, 1991.

[b]These volume estimates represent the quantity of in-place contaminated materials; the waste volumes resulting from remedial action activities may be larger or smaller depending upon the selected remedy and treatment technology utilized. All values are preliminary and are being updated as site characterization activities proceed. All values are given to two significant figures.

[c]By-product material is defined in Section 11e(2) of the Atomic Energy Act of 1954 (P.L. 83-703) as the tailings or waste products produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.

[d]Includes TRU mixed wastes. The radioactive characteristics of TRU wastes dictate the methods by which these materials need to be treated, handled, stored, and disposed.

[e]No volume estimates are available.

Table 6.3. Estimated volumes of radioactive solid waste from environmental restoration activities[a,b]

ER Programs	Waste volume, m^3					
	LLW	Mixed LLW	By-product[c]	Mixed by-product[c]	TRU[d]	Total
Southwestern Programs						
Nevada Field Office	8,200					8,200
Albuquerque Labs	19,000	330				19,000
Albuquerque Production	29,000					29,000
UMTRA (UMTRAP)			340,000			340,000
Grand Junction Projects Office						
Rocky Flats Plant (RFP)[e]						
Northwestern Programs						
Richland Field Office	840,000	300,000				1,100,000
San Francisco Field Office	11,000	15			120	11,000
Idaho Field Office	10,000	1,200			3,800	15,000
Eastern Programs						
Oak Ridge Field Office	36,000	120,000			260	160,000
Weldon Spring (WSSRAP)			420,000			420,000
FUSRAP	4,600	27	950			6,000
Fernald (FEMP)	4,700		230,000	7,600		240,000
Chicago Field Office	4,900	17,000			20	22,000
Battelle Columbus Labs (BCLDP)	2,100	88			1,300	3,500
Savannah River Field Office	550	1,100		25	140	1,800
Total	970,000	440,000	991,000	7,600	5,600	2,400,000

[a]Estimated as of December 31, 1991.

[b]These volume estimates represent the quantity of in-place contaminated materials; the waste volumes resulting from remedial action activities may be larger or smaller depending upon the selected remedy and treatment technology utilized. All values are preliminary and are being updated as site characterization activities proceed. All values are given to two significant figures.

[c]By-product material is defined in Section 11e(2) of the Atomic Energy Act of 1954 (P.L. 83-703) as the tailings or waste products produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.

[d]Includes TRU mixed wastes. The radioactive characteristics of TRU wastes dictate the methods by which these materials need to be treated, handled, stored, and disposed.

[e]No volume estimates are available.

Table 6.4. UMTRAP site descriptions, status, scheduled duration, and estimated waste volumes[a]

State and site (last operation)	Site area (ha)	Remedial action status and scheduled duration as of Dec. 31, 1991	Estimated waste volume (m^3)
Arizona			
Monument Valley (1968)	11.0;[b] 11.5[c]	Pending (38% complete); project will restart in July 1992/24 months	NA[d]
Tuba City (Sept. 1966)	8.9;[b] 128.3[c]	Completed in 1990	1,260,000
Colorado			
Durango (Mar. 1963)	51	Completed in 1991[e]	2,040,000
Grand Junction (Mar. 1970)	23.9;[b] 26.3[c]		3,580,000
Phase I[f]		Completed	
Phase II[g]		In progress (43% complete)	
Gunnison (Apr. 1962)	14.2;[b] 15[c]	Planned; Apr. 1992/28 months	655,000
Maybell (Nov. 1964)	29.7;[b] 69.2[c]	Planned; Apr. 1993/18 months	2,430,000
Naturita (1963)	h; 20.2[c]	Planned; Apr. 1993/17 months	452,000
New Rifle (Dec. 1972)	12.9;[b] 29.9[c]		3,130,000[i]
Phase I[f]		Completed	
Phase II[g]		Pending; Apr. 1992/38 months	
Old Rifle (1958)	5.5;[b] 18.8[c]		
Phase I[f]		Completed	
Phase II[g]		Pending; Apr. 1992/38 months	
Slick Rock – NC site (1957)	2.4;[b] 7.6[c]	Planned; Apr. 1993/17 months	472,000[j]
Slick Rock – UC site (1961)	7.7;[b] 26.3[c]	Planned; Apr. 1993/17 months	
Idaho			
Lowman (1960)	5.0;[b] 7.0[c]	Completed in 1991	101,000
New Mexico			
Ambrosia Lake (Apr. 1963)	44.9;[b] 230.7[c]		3,500,000
Phase I[f]		Completed	
Phase II[g]		Pending; Aug. 1991/29 months	
Shiprock (Aug. 1968)	29.1[b]	Completed in 1986	2,140,000
North Dakota			
Belfield (Oct. 1965)[k]	k; 14[c]	Planned; Apr. 1993/6 months	121,000[l]
Bowman (Feb. 1967)[k]	k; 26[c]	Planned; Apr. 1993/6 months	
Oregon			
Lakeview (1961)	16.2[b]	Completed in 1987	731,000
Pennsylvania			
Canonsburg (1957)	11.6[b]	Completed in 1985	226,000
South Dakota			
Edgemont[m]	NA[n]	Completed in 1988	34,400
Texas			
Falls City (Aug. 1973)	59.1;[b] 123.4[c]	Planned; Feb. 1992/36 months	4,170,000
Utah			
Green River (Jan. 1961)	3.6;[b] 16.3[c]	Completed in 1989	301,000
Mexican Hat (1965)	28.3;[b] 73.4[c]	Pending; April 1993/24 months	2,780,000[o]
Salt Lake City (Feb. 1964/July 1968)	24.3[b]	Completed in 1987	2,080,000[p]

Table 6.4 (continued)

State and site (last operation)	Site area (ha)	Remedial action status and scheduled duration as of Dec. 31, 1991	Estimated waste volume (m^3)
Wyoming			
Converse County (June 1965)	2.0;[b] 6.3[c]	Completed in 1989	240,000
Riverton (mid-year 1963)	29.1;[b] 56.7[c]	Completed in 1989	1,430,000
Total			31,873,400

[a]Data reported in refs. 7 and 8.
[b]Tailings site area.
[c]Other wastes site area.
[d]Not applicable. Waste volume included with that provided for Mexican Hat, Utah.
[e]Rock cover finalized in summer of 1991.
[f]Preparatory work (road construction and/or structure demolition).
[g]Storage of mill tailings or other waste.
[h]Tailings moved from site during 1977-1979; only contaminated soil remains. Mill area susceptible to flooding.
[i]Includes waste volume for Old Rifle, Colorado.
[j]Includes waste volume for Slick Rock, Colorado (UC site).
[k]No tailings; uraniferous lignite ashing plant; ore roasted and shipped away.
[l]Includes waste volume for Bowman, North Dakota.
[m]Vicinity properties only.
[n]Not applicable. Waste buried in a permanently capped cell repository a few miles south of Edgemont.
[o]Includes waste volume for Monument Valley, Arizona.
[p]Tailings were relocated 80 miles southwest of Salt Lake City near Clive, Utah.

Table 6.5. Projected volume and ^{226}Ra concentration in wastes at uncompleted UMTRAP sites as of December 31, 1991[a]

State and site	Estimated waste volume (m^3)	Radioactivity ^{226}Ra (pCi/g)
Arizona		
Monument Valley	NA[b]	49
Colorado		
Grand Junction	3,580,000	665
Gunnison	655,000	314
Maybell	2,430,000	187
Naturita	452,000[c]	46
Rifle	3,130,000	750
Slick Rock	472,000	200
Subtotal	10,719,000	
New Mexico		
Ambrosia Lake	3,500,000	455
North Dakota		
Belfield/Bowman	121,000[d]	45
Texas		
Falls City	4,170,000	200
Utah		
Mexican Hat	2,780,000	700
Total	21,290,000	

[a]Data reported in refs. 7 and 8.
[b]Not applicable. Waste volume included with that provided for Mexican Hat, Utah.
[c]Contaminated soil only.
[d]No tailings, uraniferous lignite ashing plant; ore roasted and shipped away.

Table 6.6. FUSRAP site descriptions, status, schedule, and volume of stored wastes[a]

State and site	Site area (ha)	Remedial action status and schedule as of Dec. 31, 1991	Volume of stored waste, m^3	
			Permanent	Interim
California				
Gilman Hall, Univ. of California, Berkeley	b	Completed in FY 1982	23	
Connecticut				
Seymour Specialty Wire	b	Planned in FY 1992		
Illinois				
Laboratories at Univ. of Chicago, Chicago	b	Completed in FY 1987	35	
National Guard Armory, Chicago	b	Completed in 1987	15	
Maryland				
W. R. Grace and Company, Curtis Bay	1.6	Planned in FY 2003-2004		
Massachusetts				
Shpack Landfill, Norton	3.2	Planned in FY 1993		
Ventron, Beverly	1.2	Partially completed; to be completed in FY 1994-1995	176	
Missouri				
St. Louis Airport, St. Louis	8.8	Partially completed; to be completed in FY 1997-1998		
St. Louis Airport (Vicinity Properties), St. Louis	b	Planned in FY 1996-1998		
Latty Avenue Properties, Hazelwood	b	Partially completed; to be continued through 2001		24,200[c]
St. Louis Downtown Site, St. Louis	18.2	Planned in FY 1998-2002		
Michigan				
General Motors, Adrian	b	Planned in FY 1998		
New Jersey				
E. I. du Pont de Nemours and Co., Deepwater	283	Planned in FY 2000		
Kellex Research Facility, Jersey City	6.2	Completed in FY 1981	209	
Middlesex Municipal Landfill, Middlesex	1.2	Completed in 1986		23,900[d]
Middlesex Sampling Plant, Middlesex	3.9	Partially completed; to be completed in FY 2003-2005		26,900[e]
W. R. Grace/Sheffield Brook/other properties, Wayne and Pequannock	b	Partially completed; to be continued through FY 2007		29,400[f]
Stepan Chemical Co., Ballod property and private properties on Latham St. and Davidson Ave., Maywood	b	Partially completed; to be continued through FY 2009		26,700[g]
New Brunswick Laboratory, New Brunswick	b	Partially completed; to be completed in FY 2007-2008		
New Mexico				
Acid/Pueblo/Los Alamos Canyons, Los Alamos	51.6	Completed in FY 1982	298	
Bayo Canyon, Los Alamos	137	Completed in FY 1982	1,160[h]	
Chupadera Mesa, White Sands Missile Range	b	None required[i]		

Table 6.6 (continued)

State and site	Site area (ha)	Remedial action status and schedule as of Dec. 31, 1991	Volume of stored waste, m^3	
			Permanent	Interim
New York				
Linde Air Products Div., Tonawanda	22.2	Planned in FY 1995-1996		
Colonie Interim Storage Site, Colonie	b	Partially completed; to be continued through FY 1994		918[j]
Niagara Falls Storage Site (Vicinity Properties), Lewiston	b	Completed in FY 1986		38,200[k]
Niagara Falls Storage Site, Lewiston	77	Partially completed; to be completed in FY 1993-1995		157,000[l]
Ashland Oil Co. (No. 1), Tonawanda	3	Planned in FY 1995		
Ashland Oil Co. (No. 2), Tonawanda	1	Planned in FY 1996		
Seaway Industrial Park, Tonawanda	4.8[m]	Planned in FY 1996-1997		
Baker and Williams Warehouses, New York	b	Partially completed; to be completed in FY 1993	2.5	
Oregon				
Albany Metallurgical Research Center, Albany	b	Completed in FY 1991	2,730	
Pennsylvania				
Aliquippa Forge, Aliquippa	0.34[n]	Partially completed; to be completed in FY 1993		
Tennessee				
Elza Gate, Oak Ridge	8.9	Partially completed; to be completed in FY 1992[o]	6,720	
Total (all sites)			11,368.5	327,218

[a]Data reported in ref. 10.
[b]Not determined.
[c]24,200 m^3 of waste in interim storage on-site.
[d]23,900 m^3 of waste transferred to Middlesex Sampling Plant for interim storage.
[e]26,900 m^3 of waste in interim storage on-site. Does not include 23,900 m^3 of Middlesex Municipal Landfill waste that is also stored on-site.
[f]29,400 m^3 of off-site property waste transferred to interim storage on-site.
[g]26,700 m^3 of waste in interim storage on-site.
[h]Stabilized in situ.
[i]Based on a radiological survey, it was determined that this site does not require any remedial action.
[j]918 m^3 of off-site property waste transferred to interim storage on-site.
[k]38,200 m^3 of off-site property waste transferred to interim storage on-site.
[l]Construction of the final cap is dependent upon final resolution concerning disposal of certain residues currently contained in the waste containment structure.
[m]Existing waste in the Seaway Landfill will remain in place based on pathway analysis findings.
[n]Total floor area that was surveyed; only isolated patches of radioactive contamination were found.
[o]On-site remedial action has been completed. Finalization of documentation to close out remedial action is in progress.

Table 6.7. Projected waste characteristics at uncompleted FUSRAP sites as of December 31, 1991[a]

State and site	Estimated waste volume (m^3)	Principal constituents	Major radioactive contaminants
Connecticut			
Seymour Specialty Wire	19	Rubble, metal	^{238}U
Maryland			
W. R. Grace and Company, Curtis Bay	27,500	Soil	^{232}Th
Massachusetts			
Shpack Landfill, Norton	7,190	Soil, concrete, metal, and rubble	^{238}U, ^{235}U, ^{226}Ra, ^{210}Pb
Ventron, Beverly	5,170	Soil, concrete, rubble, metal, and building material	^{238}U
Subtotal	12,360		
Missouri			
St. Louis Airport	191,000	Soil	^{238}U, ^{230}Th, ^{226}Ra
St. Louis Airport (Vicinity Properties), St. Louis	145,000	Soil	^{238}U, ^{226}Ra
Latty Avenue Properties, Hazelwood	137,000	Soil, rubble	^{238}U, ^{231}Pa, ^{230}Th, ^{227}Ac, ^{226}Ra
St. Louis Downtown Site, St. Louis	188,000	Soil, building material, and rubble	^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{222}Rn
Subtotal	661,000		
Michigan			
General Motors, Adrian	153	Soil, building material, and metal	^{238}U
New Jersey			
E. I. du Pont de Nemours and Co., Deepwater	6,320	Soil, building material, rubble, and, road material	^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb
Middlesex Sampling Plant, Middlesex	16,800	Soil, building material, and rubble	^{238}U, ^{232}Th, ^{226}Ra
W. R. Grace/Sheffield Brook/other properties, Wayne and Pequannock	53,900	Soil, rubble	^{238}U, ^{232}Th, ^{228}Th, ^{226}Ra
Stepan Chemical Co., Ballod property and private properties on Latham St. and Davidson Ave., Maywood	275,000	Soil, rubble	^{235}U, ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K
New Brunswick Laboratory, New Brunswick	3,440	Soil, rubble	^{241}Am, ^{239}Pu, ^{238}U, ^{235}U, ^{226}Ra
Subtotal	355,613		

Table 6.7 (continued)

State and site	Estimated waste volume (m^3)	Principal constituents	Major radioactive contaminants
New York			
Linde Air Products Div., Tonawanda	20,500	Soil, building material, and equipment	^{238}U, ^{232}Th, ^{230}Th, ^{226}Ra
NL Bearings Plant and private properties on Central, Palmer, and Yardboro Avenues, Albany/Colonie	9,940	Soil, building material, equipment, and rubble	^{238}U, ^{226}Ra
Ashland Oil Co. (No. 1), Tonawanda	64,200	Soil	^{238}U, ^{232}Th, ^{226}Ra
Ashland Oil Co. (No. 2), Tonawanda	14,800	Soil	^{238}U, ^{232}Th, ^{226}Ra
Seaway Industrial Park, Tonawanda	89,500	Soil	^{226}Ra
Baker and Williams Warehouses, New York City	61	Building material	^{238}U
Subtotal	199,001		
Pennsylvania			
Aliquippa Forge, Aliquippa	29	Soil, concrete, metal	^{238}U, alpha, beta-gamma
Tennessee			
Elza Gate, Oak Ridge	80	Soil, concrete, building material, and plumbing	^{238}U, ^{226}Ra
Total (all sites)	1,255,602		

[a]Data reported in ref. 10.

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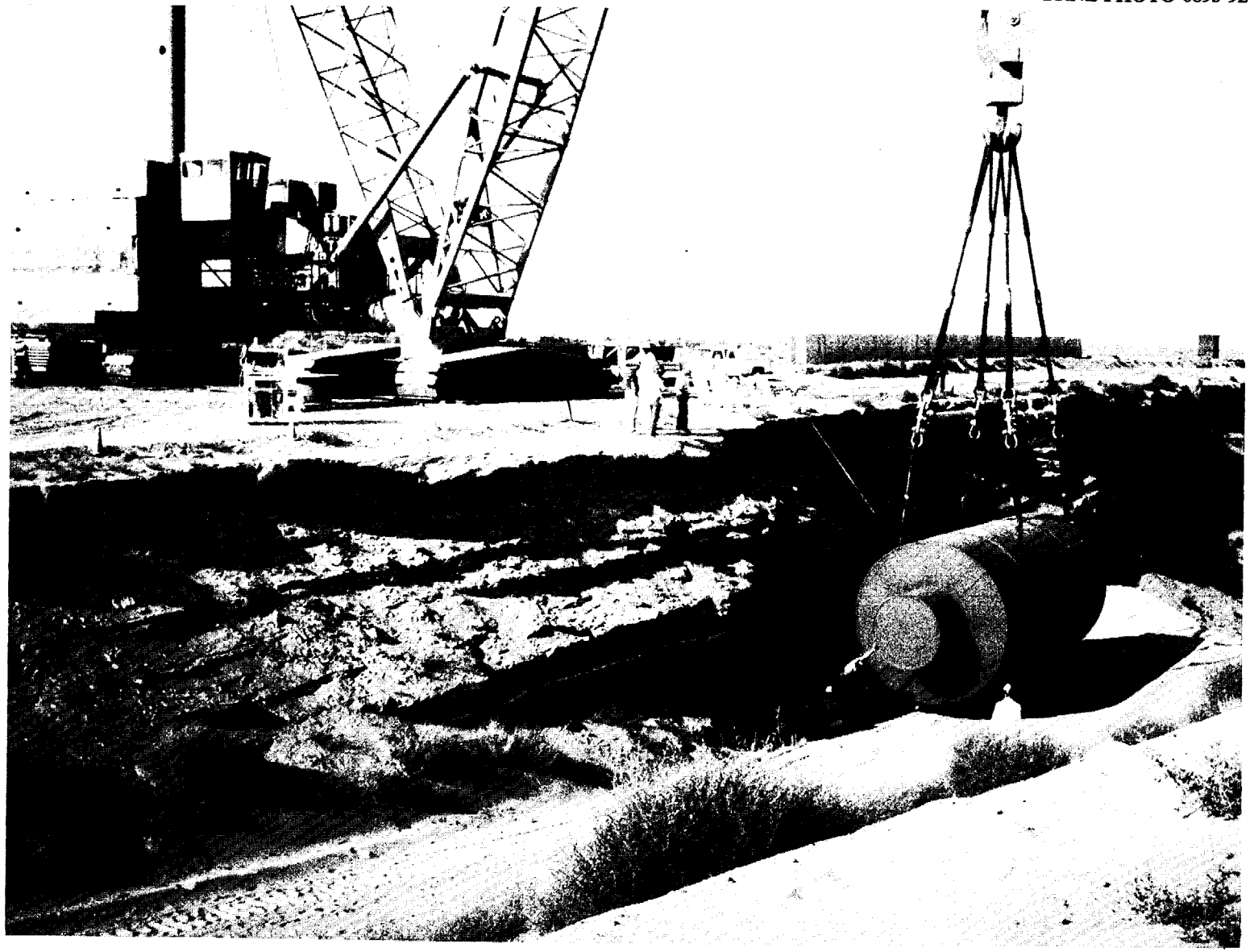

Photo 7.1. Burial of the 290-ton Pathfinder boiling-water reactor vessel at a low-level radioactive waste disposal site on August 27, 1991. (Courtesy of the Northern States Power Company, Minneapolis, Minnesota.)

7. COMMERCIAL DECOMMISSIONING WASTES

7.1 INTRODUCTION

At the end of their useful life, commercial nuclear facilities must be shut down and decommissioned. A schedule of historical and projected commercial LWR shutdowns, based on refs. 1 and 2, is given in Table 7.1. The projected volume, radioactivity, and thermal power of various types of waste generated from future commercial power LWR decommissioning activities are reported in Table 7.2. These waste projections are in addition to those previously reported in Chapter 4 (for LLW) and in Chapter 6 (for environmental restoration activities). This approach is taken mainly because the timing associated with future decontamination and decommissioning (D&D) activities at commercial power reactor sites is uncertain. The projected waste data shown in Table 7.2 are based on the projected LWR shutdown schedule given in Table 7.1 and decommissioning waste source terms developed from refs. 3–9. These projections also assume a 4-year period for decommissioning, beginning 2 years after reactor shutdown to allow sufficient preparation time for D&D operations. It was further assumed that the D&D wastes will be sent to disposal sites in four equal volumes during the 4 years of facility decommissioning. The power reactor shutdown schedule presented in Table 7.1 is based on utility estimates of reactor lifetime. Actual decommissioning schedules may be significantly different from those used herein if any of the following are implemented:

- reactors are upgraded to extend their operating lifetimes,
- significant radioactivity decay time is allowed before decommissioning operations begin, or
- the last core of spent fuel is required to remain on site for a minimum period (possibly several years) prior to shipment.

Estimates of wastes from decommissioning reference commercial LWRs and supporting fuel cycle facilities (for uranium conversion, enrichment, and fuel fabrication) are given in Table 7.3 (data from refs. 3–12). Most of these estimates assume a 40-year facility operating life. (In practice, the operating lifetime can vary significantly, depending on the extent to which facility equipment is periodically upgraded or retrofitted.) Not shown in this table are the radioactive wastes that will result from decommissioning of research, training, and test reactors.[13,14] However, the total volumes of these wastes are not expected to be significant, since such reactors are much smaller than commercial power reactors.

7.2 WASTE CHARACTERIZATION

The LWR decommissioning wastes can be grouped into three major categories:[4,7] (1) neutron-activated wastes, (2) surface-contaminated wastes, and (3) miscellaneous radioactive wastes.

Neutron-activated materials generally include the reactor vessel and its internal components (e.g., core support assemblies, control rod guide tubes) and the inner portion of the biological shield. Contaminated materials include much of the piping and equipment in the reactor containment, fuel, and auxiliary control buildings. In addition, some of the concrete surfaces of these buildings are expected to be radioactive and will require removal. The miscellaneous radioactive waste category consists of a small, but significant, group of materials that includes both "wet" and "dry" solid wastes. Wet radioactive wastes result from the processing of chemical decontamination solutions and contaminated water. These wastes include spent ion-exchange resins, cartridge filters, and evaporator and concentrator bottoms. Dry radioactive wastes include discarded contaminated items, such as rags and wipes, tools, and protective clothing. Many reactor items with surface contamination can be decontaminated,[15] rendering most of the material nonradioactive and producing a smaller, more concentrated volume of waste containing the radioactivity. Waste decontamination requires the appropriate technology and a defined level of radioactivity at which a waste is below an acceptable level of contamination. Establishing such criteria is complicated because there are varying levels of natural radioactivity. Minimum regulatory levels have already been defined in Europe;[16] the EPA, which has responsibility for defining such levels in the United States, began a review of criteria in 1984. Currently, the NRC handles requests to declare a waste below regulatory concern on a case-by-case basis. Depending on the level of technology and the minimum regulatory level definition, actual decommissioning waste volumes could vary somewhat from the estimates reported

in Table 7.3. However, the total radioactivity in the D&D waste from a particular facility is not expected to change significantly from that projected.

A list of the larger commercial power reactors that have undergone some mode of decommissioning to date is provided in Table 7.4 (data from refs. 2 and 17). (A comprehensive listing of all types of domestic reactors that have been shut down or dismantled is given in ref. 2.) As described in ref. 18, the NRC has defined the three major alternative classifications for decommissioning of nuclear facilities:

- DECON. This is defined as ". . . the alternative in which the equipment, structures and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations."

- SAFSTOR. This is defined as ". . . the alternative in which the nuclear facility is placed and maintained in such condition that the nuclear facility can be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use."

- ENTOMB. This is defined as ". . . the alternative in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombment structure is appropriately maintained, and continued surveillance is carried out until the radioactivity decays to a level permitting unrestricted release of the property." (This alternative would be allowable for nuclear facilities contaminated with relatively short-lived radionuclides such that all contaminants would decay to levels permissible for unrestricted use within a period on the order of 100 years.)

Decommissioning operations collect LLW plus a small volume of high-activity wastes from certain reactor core internal parts. These high-activity wastes are often referred to as "high-activity activation wastes." Under NRC rules, many of these wastes would be classified as greater-than-Class-C (GTCC) LLW. Some GTCC wastes contain significant concentrations of long-lived, nontransuranic radioisotopes, such as ^{59}Ni, ^{63}Ni, and ^{94}Nb. These isotopes are generated by long-term irradiation of stainless steel and some other alloys used for reactor core structural components. Because the method of waste disposal for these reactor internals is different from LLW disposal, GTCC wastes are reported separately. Under current NRC regulations,[19-20] these wastes are considered not generally acceptable for shallow-land disposal. Such wastes must be put into a federal geologic repository unless the NRC approves an alternative disposal in a licensed site. High-activity activation wastes from the immediate decommissioning of LWRs are estimated to make up less than 1% of the total waste volume, but they contain more than 95% of the radioactivity.[4,7] Such reactor wastes are comprised of many long-lived radionuclides. Most of this radioactivity is in a single reactor component, the stainless steel core shroud that surrounds the reactor fuel.

As reported in ref. 21, a study of reactor decommissioning wastes is being made by the Pacific Northwest Laboratory for the NRC. This study includes an analysis of wastes from the Shippingport Station decommissioning and an analysis of neutron-activated metal components (GTCC materials) from the internals of other reactors. Thus far, the waste characterization assessments from this study have indicated the following:

- All reactor decommissioning materials, except the pressure vessel internals, have the potential for being disposed of as Class-A LLW;
- Fission products and TRU radionuclides are absent; and
- Most radioactivity results from neutron-activation products, of which ^{60}Co is the principal contributor.

Additional updated information on the radioactive characteristics of commercial reactor D&D wastes (in particular, spent LWR control rod assemblies) will be documented in future supplements to ref. 21.

7.3 INVENTORIES AND PROJECTIONS

Of the reactors listed in Table 7.4, only three, the Elk River station, the Santa Susana sodium reactor, and the Shippingport station (discussed later), have been completely dismantled. A summary of the wastes from decommissioning the Elk River station is provided in Table 7.5 (data from refs. 22–24). Types and volumes of wastes from decommissioning the Santa Susana reactor are reported in Table 7.6 (data from ref. 25).

For the projections listed in Table 7.2, a 6-year period for decommissioning activities is assumed: 2 years for planning and preparation and 4 for actual decommissioning, with wastes generated equally over the final 4 years. The option does exist, however, to delay decommissioning for 10 to 60 years after reactor shutdown to allow significant radioactive decay.[18] For example, radioactivity levels in PWR piping have been estimated to decrease, in 10 years, to 8.7% and, in 30 years, to 0.63% of the radioactivity levels at the time of reactor shutdown. At PWR shutdown and for about 4 years thereafter, ^{55}Fe and ^{60}Co control the radiation levels; from 4 to about 100 years, ^{60}Co and ^{63}Ni control radiation levels; and well beyond 100 years, ^{59}Ni and ^{94}Nb control radiation levels.[7] The choice between immediate or delayed decommissioning involves cost trade-offs between the costs of storage with delayed decommissioning versus the higher costs resulting from the higher radiation levels associated with rapid decommissioning.[26] Therefore, the start of

actual decommissioning may be much later than the shutdown date (Table 7.1) to allow plant radiation levels to decay to lower levels. Another consideration is that the last core of discharged spent fuel may need to remain at the reactor site for at least 5 years prior to shipment. Table 7.7 shows the effects of various decommissioning alternatives on the volumes and radioactivities of D&D wastes from a reference BWR[3-5] and a reference PWR.[6-8] For cases involving deferred D&D activities, it is evident that both the volumes and activities of wastes significantly decline after a safe storage period of 50 years.

Inventories and projections of wastes from three major DOE decommissioning programs are summarized in Tables 7.8, 7.9, and 7.10 (data from refs. 27–29). The first of these tables lists waste inventory and projection data for completed decommissioning activities at the Shippingport Station Decommissioning Project, site of the first domestic commercial power reactor. The facility was shut down in 1982, and physical dismantling began in September 1985. During April 1989, the decommissioned reactor pressure vessel from the Shippingport Station was received for disposal at the Hanford site after an 8000-mile water journey. The pressure vessel was the last major reactor component to be shipped from the facility. Shippingport decommissioning activities were completed in 1990.[27]

Table 7.9 (data from ref. 28) presents a summary of the West Valley Demonstration Project (WVDP), formerly a commercial fuel reprocessing facility. Since startup of the project in 1982, more than 70% of the original process building's cell surface areas have been decontaminated and released for project reuse.

Inventories and projections of wastes from decontamination activities at the damaged Three Mile Island-Unit 2 reactor are summarized in Table 7.10. Removal of core debris from the damaged reactor started in January 1986 and was completed in April 1990. This resulted in the shipment of 155.9 t of core debris to INEL for R&D testing and storage. TMI-Unit 2 is currently scheduled to have Post Defueling Monitored Storage (PDMS) preparation activities completed by the end of 1993. Imitation of PDMS activities will require NRC approval of a submitted licensing change request.[29]

Decommissioning waste projections are being compiled on several other reactors and a fuel fabrication plant. The reactors include Dresden Unit 1, La Crosse, Saxton, Humboldt Bay Unit 3, Diablo Canyon Units 1 and 2, Rancho Seco, Fort St. Vrain, Peach Bottom (HTGR and BWR units), Pathfinder, and Shoreham.

The Commonwealth Edison Company has issued a decommissioning plan and environmental report[30] for the Dresden Unit 1 nuclear power station. Commonwealth Edison plans to decommission this reactor by first placing the facility in a SAFSTOR condition until Dresden Units 2 and 3 are ready for decommissioning. If an extended life program for Units 2 and 3 is not initiated, all three Dresden units will be decommissioned by dismantling, beginning in 2017. A summary of projected radioactive materials from the SAFSTOR decommissioning of the Dresden Unit 1 station is given in Table 7.11 (data from refs. 30 and 31).

The La Crosse BWR was shut down in 1987 and placed in SAFSTOR in 1988. Current plans are to dismantle the reactor after a SAFSTOR period of 25 years. Projected volumes and associated activities of annual waste shipments from this reactor during this period are given in Table 7.12 (data from ref. 32).

The Saxton Nuclear Experimental Reactor is a 3-MW(e) PWR that was placed in SAFSTOR following its shutdown in 1972. Work on dismantling the reactor site (DECON) started in 1986. To date, decontamination activities have been completed of the control room and radwaste building. The reactor containment building is not scheduled for dismantling until the mid-1990s. A summary of projected waste characteristics from dismantling the Saxton site is provided in Table 7.13 (data from ref. 33).

Projections of decommissioning wastes from reactors owned and operated by the Pacific Gas and Electric Company are provided in Tables 7.14 and 7.15. The waste data reported in these tables are based on decommissioning studies made of the 65-MW(e) Humboldt Bay Unit 3 BWR[34] and the 1100-MW(e) Diablo Canyon PWR Units 1 and 2.[35] Projections for the Humboldt Bay BWR in Table 7.14 include wastes from completely dismantling the reactor following a SAFSTOR period of 30 years (i.e., SAFSTOR with delayed DECON). Projections for the Diablo Canyon units in Table 7.15 reflect wastes from immediate dismantlement (DECON) of these reactors following a 30-year period of operation. Units 1 and 2 were started up in 1985 and 1986, respectively.

The Rancho Seco reactor is a 918-MW(e) PWR that was shut down in 1989. Table 7.16 (data from ref. 36) lists projected volumes of wastes from the dismantlement of this reactor following a SAFSTOR period of about 20 years.

Projections of wastes from DECON (dismantling) of the 330-MW(e) Fort St. Vrain HTGR are reported in Table 7.17 (data from refs. 37 and 38). This reactor was shut down in August 1989.

The 40-MW(e) Peach Bottom HTGR (Unit 1) was shut down in 1974 and placed in SAFSTOR. To put the reactor in this mode of decommissioning, 490 containers of solid radioactive waste were packaged and shipped. This solid waste represented a total volume of nearly 400 m^3 and an activity level of 380 Ci. In addition, about 1.14 m^3 (300 gal) of liquid waste, consisting of contaminated oil, were processed or solidified.[39]

Projections of decommissioning wastes have been made for the 1065-MW(e) Peach Bottom BWRs (Units 2 and 3). These are reported in Table 7.18 (data from ref. 40) for a case involving prompt removal and reactor dismantling (DECON).

The 66-MW(e) Pathfinder BWR was placed in the SAFSTOR mode following its shutdown in 1967. Work on dismantling the reactor (DECON) began in July 1990.

The scope of this phase of decommissioning includes the reactor building, the fuel handling building, the fuel transfer tube and vault, and the surrounding areas. By May 1991, most of the piping, pumps, tanks, wiring, ventilation, and miscellaneous systems were removed and disposed of. The reactor vessel was lifted out of containment on May 14, 1991. The decommissioning team shipped the vessel via rail later in 1991. Upon completion of this phase of decommissioning in 1992, only trace amounts of residual contamination will remain in the operating, converted fossil plant. Waste inventories and projections from D&D activities at the Pathfinder Reactor site are given in Table 7.19 (data from ref. 41).

The 820-MW(e) Shoreham BWR underwent low-power tests until 1989, when the plant's owner, Long Island Lighting Company, agreed to sell the plant to the state of New York for decommissioning. A proposed decommissioning plan (ref. 42) for the Shoreham plant has been prepared and is being reviewed by the NRC. Estimates of decommissioning wastes reported in the Shoreham decommissioning plan are presented in Table 7.20. The volume estimates in this table are conservative because they do not take credit for any volume reduction techniques and, further, because they assume no systems or structures will be decontaminated below the release criteria in place. It is also assumed that even with decontamination, all contaminated systems and the reactor pressure vessel and its internals will need to be dismantled and disposed of off-site.[42]

Table 7.21 (data from ref. 43) reports projections of wastes from decommissioning the Indian Point Unit 1 reactor. This 265-MW(e) PWR was shut down in 1974 and later placed in SAFSTOR. The projections of Table 7.21 pertain to a case of complete dismantlement (DECON) of the Unit 1 station upon completion of its SAFSTOR phase, which will be when the Unit 2 (PWR) station is finally shut down.

Inventories and projections of wastes from decommissioning activities at the Cimarron (Oklahoma) Fuel Fabrication Facility are provided in Table 7.22 (data from ref. 44). Decontamination work at this fabrication plant is scheduled to be completed during 1993.

Currently, the total impact of wastes from D&D activities at commercial reactor and fuel cycle sites has been small. However, this will become more significant after the year 2000, when more of the older reactors complete their campaign of operation.

In addition to wastes from the decommissioning of commercial reactor and fuel cycle facilities, there will be some resulting from Department of Defense power plant decommissioning operations. During a period spanning 20 to 30 years, approximately 100 nuclear-powered submarines of the U.S. Navy may be taken out of service and consigned to permanent disposal after removal of spent fuel. Current plans are to dispose of the submarine reactor compartments by land burial at government-owned LLW burial sites. Each reactor compartment contains about 1000 t of metal, and it is estimated that 100 reactor compartments can be buried on 4 ha (10 acres) of land.[45] As of the end of 1991, 40 submarines had been taken out of active service. In 20 of these submarines, the reactor compartment was first defueled, then later removed and disposed of at a government burial site. (LLW disposed from these activities is included in the DOE site inventories reported in Chapter 4.) The remaining 20 submarines with reactor compartments were being held in protective storage.[2]

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Table 7.1. Schedule of final shutdown dates for commercial light-water reactors[a,b]

Calendar year of shutdown	BWR		PWR		Total LWR	
	No.	MW(e)	No.	MW(e)	No.	MW(e)
1963	1	5			1	5
1967	1	66	1	17	2	83
1968	2	39			2	39
1972			1	3	1	3
1974			1	265	1	265
1976	1	65			1	65
1978	1	200			1	200
1979			1	926[c]	1	926
1982			1	72	1	72
1987	1	48			1	48
1989	1	820	1	918	2	1,738
Totals through 1991	8	1,243	6	2,201	14	3,444
2000			1	175	1	175
2003	1	72			1	72
2007			2	1,018	2	1,018
2009	2	1,270	1	490	3	1,760
2010	2	1,454	2	1,197	4	2,651
2011	2	1,339	1	805	3	2,144
2012	4	2,747	4	2,803	8	5,550
2013	1	1,065	9	7,314	10	8,379
2014	6	5,288	5	3,620	11	8,908
2015	2	1,642	4	3,875	6	5,517
2016	2	1,886	5	4,590	7	6,476
2017			3	2,560	3	2,560
2018	1	784	3	2,919	4	3,703
2020			2	2,055	2	2,055
2021			4	4,272	4	4,272
2022	2	2,187	2	1,970	4	4,157
2023			3	3,064	3	3,064
2024	4	4,537	2	2,257	6	6,794
2025	3	3,084	6	6,908	9	9,992
2026	2	2,383	3	3,565	5	5,948
2027	2	2,013	6	6,431	8	8,444
2028			2	2,425	2	2,425
2029	1	1,055	2	2,319	3	3,374
2030			2	2,300	2	2,300
Projected totals (1992-2030)	37	32,806	74	68,932	111	101,738

[a]Data from refs. 1 and 2.

[b]Projected reactor shutdown dates are based on the DOE/EIA No New Orders Case. Years in which no reactor shutdown is expected are eliminated.

[c]Shutdown of Three Mile Island-Unit 2 nuclear power plant due to an accident. Upon completion of the present cleanup campaign, the plant will be placed in a monitored storage mode and will be decommissioned when TMI-Unit 1 is dismantled.

Table 7.2. Projections of cumulative volume, radioactivity, and thermal power of wastes from decommissioning commercial light-water reactors shut down during 1992-2030[a,b,c]

Waste type	Volume (m^3)	Activity (Ci)	Thermal power (W)
	Boiling-water reactors		
Class-A LLW	525,805	46,009	352
Class-B LLW	10,595	143,037	1,103
Class-C LLW	1,505	477,399	1,767
Subtotals	537,905	666,445	3,222
Greater-than-Class-C LLW[d]	281	4,733,919	29,450
Totals for D&D of BWRs	538,186	5,400,364	32,672
	Pressurized-water reactors		
Class-A LLW	1,053,693	218,859	1,150
Class-B LLW	12,554	294,567	2,593
Class-C LLW	998	251,453	1,887
Subtotals	1,067,245	764,879	5,630
Greater-than-Class-C LLW[d]	267	45,474,178	266,148
Totals for D&D of PWRs	1,067,512	46,239,057	271,778
	Total light-water reactors		
Total LLW	1,605,150	1,431,324	8,852
Greater-than-Class-C LLW	548	50,208,097	295,598
Totals for D&D of LWRs	1,605,698	51,639,421	304,450

[a]The projections of this table are based on a decommissioning scenario which assumes that upon reactor shutdown, there will be a 2-year planning period followed by a 4-year decontamination campaign, with wastes being collected equally over each of the 4 years. In terms of numerical significance, the number of digits used to report these projections is greater than justified. However, this procedure is used for bookkeeping purposes to ensure consistency in the numerical totals reported. Since these projections are based on the reactor shutdown dates reported in ref. 1 and the source terms developed from refs. 3-9 (see Appendix A), each reported number is significant to no more than three figures.

[b]This table refers only to reactors yet to be decommissioned. Historical reactor D&D wastes are included in the institutional/industrial (I/I) waste inventories reported in Chapter 4.

[c]The projections in this table are cumulative levels for year 2036, the last year in which wastes are collected from reactors shut down in year 2030.

[d]Contribution from the core shroud (see ref. 9).

Table 7.3. Projections of radioactive wastes from decommissioning reference commercial power reactors and fuel cycle facilities[a]

Fuel cycle facility	Capacity	Operation		Decommissioning alternative	Waste volume, m^3	
		Period	Lifetime (years)		LLW[b]	GTCC[c]
Boiling-water reactor	1,155 MW(e)	–	40[d]	DECON	18,938	10[e]
Pressurized-water reactor	1,175 MW(e)	–	40[d]	DECON	18,192	5[e]
Uranium conversion plant (solvent extraction process)	10,000 MTIHM/year	–	40	DECON	1,260	0
Uranium enrichment plants (gaseous diffusion plants)						
• K-25 site	7,700,000 kg SWU/year	1945-1985	40	DECON	910,112	0
• Paducah site	11,300,000 kg SWU/year	1954-2005	51	DECON	662,414	0
• Portsmouth site	8,300,000 kg SWU/year	1956-2005	49	DECON	630,093	0
Fuel fabrication plant	1,000 MTIHM/year	–	40	DECON	1,090	0

[a]Based on information reported in refs. 3-12.
[b]Class-A, Class-B, and Class-C LLW.
[c]Greater-than-Class-C LLW.
[d]Reactor operations assume a 75% capacity factor.
[e]Assumes contributions only from the core shroud. Estimated from information provided in the report DOE/LLW-114 (ref. 9).

Table 7.4. List of U.S. civilian reactors shut down or dismantled as of December 31, 1991[a]

[Reactors of 10-MW(th) capacity or greater]

Reactor facility	Location	Reactor type	Capacity rating		Year of shutdown	Decommissioning alternative selected	Present status of decommissioning alternative
			MW(e)	MW(th)			
Boiling Nuclear Superheater Power Station (BONUS)	Punta Higuera, PR	Boiling-water	17	50	1968	ENTOMB	ENTOMB
Carolinas-Virginia Tube Reactor (CVTR)	Parr, SC	Pressure-tube, heavy-water	17	64	1967	SAFSTOR	SAFSTOR
Dresden Nuclear Power Station, Unit 1	Morris, IL	Boiling-water	200	700	1978	SAFSTOR	SAFSTOR preparation[b]
Elk River Power Station	Elk River, MN	Boiling-water	22	58	1968	DECON	DECON completed[c]
Enrico Fermi, Unit 1	Lagoona Beach, MI	Sodium-cooled, fast	61	200	1972	SAFSTOR	SAFSTOR
ESADA/GE Vallecitos Experimental Superheat Reactor (Empire States Atomic Development Associates and General Electric Company)	Pleasanton, CA	Light-water, moderated	NE[d]	17	1967	SAFSTOR	SAFSTOR
Fort St. Vrain Reactor	Platteville, CO	High-temperature, gas-cooled	330	842	1989	TBD[e]	TBD
General Electric Testing Reactor	Pleasanton, CA	Tank	NE	50	1977	SAFSTOR	SAFSTOR
Hallam Nuclear Power Facility	Hallam, NE	Sodium-cooled, graphite-moderated	75	240	1964	ENTOMB	ENTOMB
Humboldt Bay Power Plant, Unit 3	Eureka, CA	Boiling-water	65	242	1976	SAFSTOR	SAFSTOR[f]
Indian Point Station, Unit 1	Buchanan, NY	Pressurized-water	265	615	1974	SAFSTOR[g]	SAFSTOR
La Crosse Nuclear Generating Station	Genoa, WI	Boiling-water	48	165	1987	SAFSTOR	SAFSTOR[h]
Pathfinder Atomic Plant	Sioux Falls, SD	Boiling-water	66	203	1967	DECON	DECON[i]
Peach Bottom Power Station, Unit 1	Peach Bottom, PA	High-temperature, gas-cooled	40	115	1974	SAFSTOR	SAFSTOR
Piqua Nuclear Power Facility	Piqua, OH	Organic-cooled and moderated	11	46	1966	ENTOMB	ENTOMB

Table 7.4 (continued)

Reactor facility	Location	Reactor type	Capacity rating MW(e)	Capacity rating MW(th)	Year of shutdown	Decommissioning alternative selected	Present status of decommissioning alternative
Plum Brook Reactor	Sandusky, OH	Tank	NE	60	1974	SAFSTOR	SAFSTOR
Rancho Seco	Clay Station, CA	Pressurized-water	918	2,915	1989	SAFSTOR	SAFSTOR preparation[j]
Saxton Nuclear Experimental Reactor Project	Saxton, PA	Pressurized-water	3	24	1972	SAFSTOR	DECON in progress[k]
Shippingport Power Station	Shippingport, PA	Pressurized-water	72	236	1982	DECON	DECON completed[l]
Shoreham Reactor	Brookhaven, NY	Boiling-water	820	2,436	1989	DECON	DECON preparation[m]
Sodium Reactor Experiment	Santa Susana, CA	Sodium-cooled, graphite-moderated	10	30	1964	DECON	DECON completed[n]
Southwest Experimental Fast Oxide Reactor (SEFOR)	Strickler, AR	Sodium-cooled, fast	NE	20	1972	SAFSTOR	SAFSTOR
Three Mile Island-Unit 2 Reactor	Londonderry Township, PA	Pressurized-water	926	2,770	1979	o	o
Vallecitos Boiling-Water Reactor (VBWR)	Pleasanton, CA	Boiling-water	5	33	1963	SAFSTOR	SAFSTOR
Westinghouse Testing Reactor (WTR)	Waltz Mill, PA	Tank	NE	60	1962	SAFSTOR	SAFSTOR
Yankee Rowe, Unit 1	Bolton, MA	Pressurized-water	175	530	1992	TBD	TBD

[a]Based on refs. 2 and 17.
[b]Estimates of decommissioning wastes are reported in Table 7.11.
[c]Decommissioning wastes are reported in Table 7.5.
[d]NE = no electricity generated by reactor before it was shut down.
[e]TBD = to be determined. Decommissioning wastes for the DECON option are reported in Table 7.17.
[f]Estimates of decommissioning wastes are reported in Table 7.14.
[g]Estimates of decommissioning wastes are reported in Table 7.21.
[h]Estimates of decommissioning wastes are reported in Table 7.12.
[i]Estimates of decommissioning wastes are reported in Table 7.19.
[j]Decommissioning wastes are reported in Table 7.16.
[k]DECON of the Saxton facility started in 1986. Estimates of decommissioning wastes are given in Table 7.13.
[l]Decommissioning wastes are reported in Table 7.8.
[m]A proposed decommissioning plan on the Shoreham reactor is undergoing review by the NRC. Estimates of decommissioning wastes are reported in Table 7.20.
[n]Decommissioning wastes are reported in Table 7.6.
[o]TMI-Unit 2 has completed defueling and decontamination in selected areas. The plant will be placed in a long-term monitored storage mode and will be decommissioned when TMI-Unit 1 is dismantled. Inventories of decontamination wastes are reported in Table 7.10.

Table 7.5. Types and quantities of wastes from decommissioning the Elk River reactor site[a,b]

Reactor component or waste type[c]	Volume (m^3)	Mass (t)	Radioactivity[d] (Ci)
Reactor pressure vessel	4.6	36.0	1,110
Reactor internals			
Upper shroud	e	e	770
Lower shroud	e	e	35
Core and shroud plate	e	e	2,370
Core support stand	e	e	100
Inner thermal shield	e	e	3,090
Shadow shields	e	e	2,330
Feedwater distribution ring	e	e	75
Subtotals (internals)	1.1	8.1	8,770
Externals	5.3	54.0	440[f]
Biological shield	5.9	39.0	5.8
Miscellaneous radioactive contaminated materials (excluding concrete)	1,350	1,090	e
Contaminated concrete	2,010	2,680	e
Totals	3,377	3,907	>10,325

[a]Based on information reported in COO-651-93 (ref. 22), BNL-NUREG-29244R (ref. 23), and ref. 24.

[b]The Elk River BWR operated from 1963 to 1968 and generated 58.29 MW(e)-years of (gross) electrical energy. The plant was decommissioned from 1971 to 1974. During this time, the reactor was completely dismantled.

[c]All decommissioning wastes were shipped to Sheffield, Illinois.

[d]Estimated at the start of decommissioning.

[e]Information not available.

[f]Includes 75 Ci estimated for the outer thermal shield of the reactor.

Table 7.6. Types and volumes of wastes from decommissioning the Santa Susana Sodium Reactor Experiment site[a,b]

Type of waste[c]	Shipping container volume, m^3					
	King-Pac[d]	Boxes[e]	Casks	Drums	Unboxed	Totals
Activated vessel components		301	20		18	339
Contaminated components		1,458	49	29	17	1,553
Contaminated soil and concrete	1,752			42		1,794
Absorbed alcohol and other solidified liquids				141		141
Disposed liquid				36		36
Totals	1,752	1,759	69	248	35	3,863

[a]Based on information reported in ESG-DOE-13403 (ref. 25). Activity data were not available.

[b]This sodium-cooled, graphite-moderated reactor operated from 1957 to 1964 and generated 4.244 MW(e)-years of (gross) electrical energy. The plant was decommissioned from 1974 to 1983. During this time, the reactor was completely dismantled.

[c]Initially, these wastes were shipped to Beatty, Nevada. Later in the decommissioning program, they were shipped to Hanford, Washington.

[d]This is a registered trademark for tri-walled cardboard containers used for packaging low-specific-activity nonmetallic wastes (e.g., contaminated soil, bedrock, and concrete rubble).

[e]Wooden boxes used for packaging low-specific-activity wood or steel.

Table 7.7. Estimated volumes and activities of wastes from decommissioning alternatives considered for reference LWRs[a,b,c]

Decommissioning alternative	Totals		Class-A LLW		Class-B LLW		Class-C LLW	
	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)	Volume (m^3)	Activity (10^3 Ci)
Reference boiling-water reactor [1,155 MW(e)]								
Immediate decontamination following shutdown	18,938	295.8	18,512	13.9	373	42.8	53	239.1
Deferred decontamination after a safe storage period of:								
30 years[d]	18,938	9.0	18,652	1.4	233	1.1	53	6.5
50 years[d]	1,736	5.9	1,450	0.2	247	1.0	39	4.7
100 years[d]	1,626	4.0	1,340	0.1	247	0.6	39	3.3
Entombment[e]	8,031	286.6	7,605	4.7	373	42.8	53	239.1
Reference pressurized-water reactor [1,175 MW(e)]								
Immediate decontamination following shutdown	18,192	124.7	17,961	37.3	214	53.1	17	34.3
Deferred decontamination after a safe storage period of:								
30 years[d]	18,195	3.6	18,055	1.5	123	0.6	17	1.5
50 years[d]	1,700	1.6	1,568	0.3	115	0.2	17	1.1
100 years[d]	1,650	1.0	1,533	0.2	100	<0.1	17	0.8
Entombment[e]	3,367	126.5	3,136	39.1	214	53.1	17	34.3

[a]From refs. 3-8. Activities were calculated from data reported in refs. 3-8. Data for each reactor are based on 40 years of operation and a capacity factor of 0.75.

[b]Based on limiting concentration of long- and short-lived radionuclides given in Tables 1 and 2 of 10 CFR 61.55.

[c]Estimates for GTCC wastes from LWR decommissioning (DECON) were recently developed by EG&G Idaho, Inc. and are reported in ref. 9. A summary of all GTCC wastes estimated in ref. 9 for LWR operations and decommissioning activities is presented in Chapter 4.

[d]Includes radioactive wastes from both preparations for safe storage and deferred decontamination.

[e]Involves the removal of reactor spent fuel (shipped to repository) followed by the encasement of the rest of the radioactive portion of the reactor facility.

Table 7.8. Characteristics of wastes from decommissioning activities at the Shippingport Station Decommissioning Project[a,b]

Type of waste	Total waste removed from the Shippingport reactor facility		
	Volume (m^3)	Mass (kg)	Activity (Ci)
Liquid	2,187	c	0.64
Solid[d]			
Reactor pressure vessel package	283	815,560	16,467
Spent resins	101	56,429	40.82
Asbestos	1,072	138,205	2.49
Compacted trash	24	12,412	0.04
Metallic waste	1,801	1,117,113	41.59
Large, one-piece components	326	455,230	24.27
Concrete	52	52,470	0.08
Lead	57	62,302	0.17
Soil	53	31,493	1.44
Solidified sludge	164	198,066	4.30
Other solids	2,123	833,976	26.54
Total solid waste	6,056	3,773,256	16,608.75

[a]Based on ref. 27.

[b]The Shippingport reactor operated from 1957 to 1982, generating 841.8 MW(e)-years of (gross) electrical energy. During its history, the reactor operated with three different cores. Two of these were light-water cooled, seed-blanket, PWR-type cores. The third and last core in the reactor was a seed-blanket LWBR-type. Physical dismantling began in September 1985 and was completed in July 1989.

[c]Information not available.

[d]Solid waste volume and mass include total volume and total mass as packaged.

Table 7.9. Inventories and projections of wastes from various activities at the West Valley Demonstration Project[a,b]

Waste description	Total wastes as of December 31, 1991	Projected total wastes upon completion of the project[c]
Spent fuel remaining[d]		
Mass, MTIHM	27	27
Number of fuel assemblies	125	125
High-level waste generated from reprocessing operations (1966-1972)[e]		
Volume, m^3 (waste form)	1,231 (liquid, sludge, and zeolite)	210 (glass)
Activity, Ci[f]	27,250,000	23,590,000[g]
Transuranic waste generated from presolidification activities and HLW vitrification		
Volume, m^3	42	300
Activity, Ci[f]	66	350
Low-level waste generated from presolidification activities and HLW vitrification		
Buried waste (1982-86) volume, m^3	5,786	15,000
Buried waste (1982-86) activity, Ci[f]	625	58,600
Stored waste volume, m^3	5,400[h]	
Stored waste activity, Ci[f]	433[i]	
Low-level waste incorporated in cement by radwaste treatment system[j]		
Stored waste volume, m^3	3,002	
Stored waste activity, Ci[f]	295	
Low-level waste from postsolidification D&D after HLW vitrification		
Volume, m^3	0	4,300
Activity, Ci[f]	0	1,400
Total low-level summary (buried and stored wastes)		
Volume, m^3	14,188	
Activity, Ci[f]	1,353	

[a]Based on data reported in ref. 28.

[b]At the West Valley Demonstration Project (WVDP) site, Nuclear Fuel Services, Inc., operated a reprocessing plant with a rated capacity of 300 MTIHM/year. During its operation from 1966 to 1972, 640 t of spent fuel were reprocessed.

[c]Wastes generated after 1987 are regarded as stored, not buried or disposed.

[d]At the end of 1990, 125 fuel assemblies (representing 27 t of spent fuel) still remained in storage at the WVDP. These assemblies are owned by DOE. The return shipment of all commercially owned spent fuel (625 fuel assemblies) to the owner utilities was completed by the end of 1986.

[e]Currently, about 2,031 m^3 of HLW is stored at the WVDP site in two underground steel tanks. Eventually, this waste will be vitrified and about 300 canisters of glass will be produced. This assumes each canister contains 0.70 m^3 of glass.

[f]Principal nuclides include ^{241}Am, ^{241}Pu, ^{137}Cs, ^{99}Tc, ^{90}Sr, and ^{63}Ni.

[g]Decayed activity for 1997.

[h]Comprised of Class A (89.5%), Class B (8.5%), and Class C (2.0%) LLW.

[i]Comprised of Class A (24.7%), Class B (64.1%), and Class C (11.2%) LLW.

[j]Comprised of Class A and Class C LLW (see Table A.10 of Appendix A).

Table 7.10. Characteristics of wastes from decontamination activities at the Three Mile Island-Unit 2 reactor site[a,b]

Type of waste	Mass shipped (t)	Total waste shipped from TMI (August 1979 through December 1991)	
		Packaged volume (m^3)	Shipment activity[c] (Ci)
Spent fuel/core debris[d]	155.9	123.9	6,911,513
Low-level and other wastes[e]			
Dry activated waste (DAW)[f]	-	5,880.1	709.94
Wet and solidified waste[g]	-	275.4	7,462.2
Submerged demineralizer system (SDS)[h]	-	58.2	673,877.7
EPICOR II system liners[i]			
First generation	-	125.7	77,750
Second generation	-	808.2	3,804
Defueling water cleanup system (DWCS)[j]	-	8.45	5,886.3
Off-site deconable scrap	-	138.9	4
Totals	155.9	7,418.85	7,681,007.14

[a]Three Mile Island (TMI)-Unit 2 is a PWR reactor with the following characteristics: rated capacity – 926 MW(e); mass of fuel in core before accident – 82 MTIHM; and number of fuel assemblies before accident – 177. The reactor began operation in 1978 and generated 231.6 MW(e)-years of (gross) electrical energy before being permanently shut down by an accident in March 1979.

[b]Based on information reported in ref. 29.

[c]These activities represent the cumulative sum of curies reported at the time of waste shipment. The values reported are not corrected for decay after the time of shipment.

[d]Defueling of the reactor started in January 1986. Fuel debris shipments were completed in April 1990.

[e]Other wastes include those regarded as "abnormal" because their classification is presently uncertain.

[f]Dry activated wastes are dry wastes packaged in drums, boxes, and high-integrity containers.

[g]Includes solidified miscellaneous liquids and miscellaneous resin liners and filters from TMI-Unit 2 systems.

[h]Resin liners and filters from the SDS (for water treatment).

[i]Resin liners and filters from the EPICOR II system that use organic ion-exchange resins and inorganic zeolite media. These include processing high-integrity containers (HICs).

[j]Resin liners and filters from the DWCS that use inorganic zeolite media. These are primarily processing HICs.

Table 7.11. Projected characteristics of radioactive wastes from Dresden Unit 1 decommissioning activities[a,b,c]

Waste category	Reactor component(s)	Volume (m^3)
Radioactive materials	Reactor vessel and internals:[d]	
	Reactor vessel	11
	Bioshield sand and concrete	239
	Thermal shield	2
	Instrumentation support tubes	1
	Bottom core support structure	1
	Other[e]	5
	Subtotal	259
	Solidified decontamination solvents	655
	Reactor station components and materials[f]	6,214
	Total	7,128
Radioactive hazardous materials	Asbestos insulation on contaminated piping and components	409
	Grand total	7,537

[a]Based on refs. 30 and 31.

[b]The 200-MW(e) Dresden BWR began operation in 1960 and generated about 1,800 MW(e)-years of (gross) electrical energy before it was shut down in 1978. The projections of this table pertain to wastes from the dismantlement of the reactor following a SAFSTOR period of about 30 years.

[c]These projections do not include 32 m^3 of LLW from SAFSTOR preparation activities (e.g., materials from cleaning spent fuel pool surfaces, miscellaneous sumps, and other contaminated areas; filters from chemical cleaning system; and miscellaneous dry active trash).

[d]The greatest source of radioactivity in the Dresden containment building is in the reactor vessel and internals. This activity results from neutron activation products in the vessel and shield materials. Reference 28 reports an estimated activity of 4,029,000 Ci for the vessel and internals when the reactor was shut down in 1978. By the year 2017, when dismantling of the reactor is to begin, this activity is projected to drop to a level of about 16,000 Ci.

[e]Other reactor internal components include steam deflector support, top grid assembly, bottom support grid, control rod guide tubes, and reactor vessel cladding.

[f]Reactor station components and materials include piping, valves, pumps, heat exchangers, building concrete, and structural steel.

Table 7.12. Inventories and projections of low-level radioactive wastes from La Crosse BWR decommissioning activities[a,b]

Calendar year(s)	Decommissioning mode	Average annual quantity of waste shipped to burial site[c,d]	
		Volume (m^3/year)	Activity (Ci/year)
1988	SAFSTOR	4.62	70.3
1989[e]	SAFSTOR	6.74	32.12
1990[e]	SAFSTOR	4.59	0.74
1991[e]	SAFSTOR	5.46	0.32
1992[e]	SAFSTOR	35.0	1.2
1993-1996	SAFSTOR	0.0	0.0
1997-1998	SAFSTOR	7.0	23
1999-2003	SAFSTOR	6.5	13
2004-2008	SAFSTOR	4.9	7
2009-2013	SAFSTOR	3.6	5
2014-2018	DECON	103.0	>280

[a]Based on the information reported in ref. 32.

[b]The 48-MW(e) La Crosse BWR began operation in 1968 and generated 462 MW(e)-years of (gross) electrical energy until it was shut down in April 1987. The reactor was placed in SAFSTOR in 1988. The data in this table are based on a SAFSTOR period of 25 years.

[c]During the SAFSTOR period, the principal types of radioactive solid waste which will be processed and shipped to a suitable disposal facility will be low-level radioactive wastes principally with radioactivity content less than Class C (10 CFR 61) wastes. These wastes will include (1) dry active wastes (DAW), normally Class A, unstable; (2) dewatered spent demineralizer resins and filtration media, normally Class A or B, stable; and (3) contaminated or irradiated plant system components, normally Class B or C, stable.

[d]Contributions from activated core components and structural materials are not included. Volume estimates of these materials are currently not available; however, a preliminary activity estimate of 12,620 Ci has been made for these activated materials for year 2014, when the reactor will be ready for dismantlement.

[e]Volume of waste for this year reflects significant reductions due to treatment. Waste shipments for this year contained DAW and contaminated metal, which were either decontaminated, supercompacted, or both by two Oak Ridge waste treatment companies (Quadrex Recycle Center and SEG).

Table 7.13. Projected volumes of wastes from Saxton PWR decommissioning activities[a,b,c]

Reactor component(s)/waste	Volume (m^3)
Reactor vessel, head, and internals	39.64
Pressurizer	3.12
Primary coolant pump	2.83
Steam generator	24.07
Demineralizers	4.25
Shutdown cooling pumps	0.85
Relief valve discharge tank	4.25
Purification system surge tank	9.91
Safety injection pumps	1.42
Cooling heat exchanger	16.99
Containment vessel sump pumps	0.85
Discharge tank drain pumps	0.85
Containment ventilation equipment	16.99
Primary piping	5.66
Auxiliary system piping and valves	28.32
Contaminated and activated concrete of containment vessel	229.37
General valves, controllers, and instrumentation	42.48
Low-level waste from disposal operations	33.98
Westinghouse supercritical test loop	42.48
Total volume	508.31

[a]Based on the information reported in ref. 33.

[b]The 3-MW(e) Saxton PWR was shut down in 1972 and placed in SAFSTOR. Work on dismantling the reactor site started in 1986. This facility operated from 1962 until 1971, generating 10.4 MW(e)-years of (gross) electrical energy.

[c]Activity data are unknown at this time. Saxton reactor decommissioning waste characteristics are still being reviewed, and additional information will be provided in this table in future reports.

Table 7.14. Projected burial volumes of radioactive wastes from SAFSTOR (mothballing/delayed dismantling) of Humboldt Bay Unit 3[a,b,c]

D&D activity/reactor component	Volume (m^3)
Spent fuel racks	63
Nuclear steam supply system removal	
Reactor vessel	71[d]
Reactor vessel internals	24[e]
Other components	17
Removal of major equipment	
Main turbine/generator	353
Main condenser	164
Disposal of contaminated plant systems	
Turbine system	425
Electrical system	153
High-pressure steam and feedwater systems	190
Condensate system	155
Radwaste collection and treatment systems	200
Other systems	248
Decontamination of site buildings	
Refueling	434
Yard piping and soil	160
Other	30
Disposal of contaminated solid waste	152
Process liquid waste[f]	63
Disposal of modified plant and off-gas systems as a result of 1986-1991 capital improvements	100
Total	3,002

[a]Based on the information reported in ref. 34.

[b]The 65-MW(e) Humboldt Bay Unit 3 BWR operated from 1963 until 1976, generating 545 MW(e)-years of (net) electrical energy. The plant was placed in a SAFSTOR mode in 1988. The projections in this table and in ref. 34 assume delayed dismantling (DECON) of the reactor begins in 2015. At this time, the SAFSTOR period will end and the current inventory of spent fuel at the site will have been shipped to a federal repository when the latter is available.

[c]Except where noted, the volumes reported represent estimates for packaged Class A LLW.

[d]Includes 53 m^3 of Class C LLW.

[e]Includes 22 m^3 of Class C LLW and 2 m^3 of GTCC waste.

[f]Class B LLW.

Table 7.15. Projected burial volumes of radioactive wastes from DECON (prompt removal/dismantling) of Diablo Canyon Power Plant PWR Units 1 and 2[a,b,c]

D&D activity/reactor component	Volume, m^3	
	Unit 1	Unit 2
Spent fuel racks	440	440
Nuclear steam supply system removal		
Steam generators	1,911	1,911
Reactor vessel	239[d]	239[d]
Reactor vessel internals	271[e]	242[f]
Other components	416	416
Disposal of plant systems		
Electrical (contaminated) system	908	765
Other systems	1,736	1,411
Decontamination of site buildings		
Fuel handling	96	96
Containment and penetration area	958	958
Other	<<1	158[g]
Disposal of contaminated solid waste	2,787	2,847
Process liquid waste	386	364
Disposal of modified plant systems based on 1986-1991 capital additions	36	108
Total	10,184	9,955

[a]Based on information reported in ref. 35. This reference recommends the DECON option on the basis of technical and financial considerations. Projections for the SAFSTOR decommissioning option are also reported in ref. 35.

[b]Commercial operation of the Diablo Canyon units began in May 1985 for Unit 1 and in March 1986 for Unit 2. Unit 1 has a net capacity rating of 1,131 MW(e), and Unit 2 has a net capacity rating of 1,156 MW(e). For the study of ref. 35, shutdown dates of these reactors are taken as 30 years following their startup dates.

[c]Except where noted, the volumes reported represent estimates for packaged Class A LLW.

[d]Includes 60 m^3 of Class C LLW.

[e]Includes 144 m^3 of Class C LLW and 127 m^3 of GTCC waste.

[f]Includes 128 m^3 of Class C LLW and 114 m^3 of GTCC waste.

[g]Includes wastes from auxiliary and radwaste storage buildings.

Table 7.16. Projected volumes of wastes from Rancho Seco PWR decommissioning activities[a,b,c]

Reactor component(s)/waste	Volume (m^3)
Spent fuel racks	359
Reactor vessel	212
Reactor vessel internals	156
Primary system components and piping	1,336
Total for reactor vessel and components	2,063
Secondary and radwaste systems	2,625
Contaminated structures	468
Processed liquid waste	98
Dry active waste	397
Grand total	5,651

[a]Based on ref. 36 (extracted from a 1991 decommissioning cost study prepared by TLG Engineering, Inc.).

[b]The 918-MW(e) Rancho Seco (Unit 1) PWR was shut down in 1989. The reactor operated from 1974 until 1989, generating 5,277.3 MW(e)-years of (gross) electrical energy.

[c]The projections in this table pertain to wastes from dismantlement of the reactor following a SAFSTOR period of about 20 years.

Table 7.17. Projected characteristics of wastes from DECON (dismantling) of the Fort St. Vrain HTGR[a,b]

Reactor component(s)/waste	Burial volume (m^3)	Activity (Ci)	Projected LLW class
Prestressed concrete reactor vessel (PCRV) system			
PCRV concrete	1,174.94	c	A
Control rod drives (CRDs)	97.81	c	A
CRD absorber strings	18.81	c	C
CRD metal clad reflector	4.04	c	C
Boronated stainless steel rods	845.27	c	B
Top cover plates	1.59	c	A
Top head kaowool[d] and liner	13.32	c	A
Core barrel	21.97	c	A
Core support blocks	41.09	c	A
Core support floor kaowool, plates, and liner	6.94	c	A
Metal clad reflector blocks (non-CRD)	28.67	c	C
Dummy fuel blocks	168.28	c	A
Graphite reflector blocks	237.65	c	A, B
Silica insulation blocks	14.27	c	A
Large permeable reflectors	709.32	c	B
Reflector keys	0.57	c	A
Metal shell for large side reflector	0.58	c	A
Radial cover plate, kaowool, and PCRV liner	55.57	c	A
Region constraint devices	1.42	c	C
Helium purification and regeneration system	30.87	c	A
Helium circulators	4.01	c	A
Steam generators	269.02	c	A, B
PCRV system total	3,746.01	1.30E+6	
Material handling, treatment, and storage (MHTS) systems			
Fuel handling machine	63.33	c	A
Fuel storage wells	28.48	c	A
Equipment storage wells	2.98	c	A
Auxiliary transfer cask	19.52	c	A
Hot service facility	10.98	c	A
MHTS systems total	125.29	3.88E-2	
Decontamination and waste (DW) systems			
Decontamination system	9.57	c	A
Radioactive liquid waste	9.15	c	A
Radioactive gas waste	32.93	c	A
Dry activated and other wastes	153.34	c	A
DW systems total	204.99	1.33E-4	
Fort St. Vrain HTGR total	4,076.29	1.30E+6	

[a]Based on refs. 37 and 38. The case considered involves complete dismantlement of all radioactive systems at the reactor site after defueling of the reactor has been completed.

[b]The 330-MW(e) Fort St. Vrain HTGR operated from 1979 until 1989, generating about 490 MW(e)-years of (gross) electrical energy.

[c]Information is not available.

[d]Kaowool is an insulation material.

Table 7.18. Projected volumes of radioactive wastes from DECON (prompt removal/dismantling) of the Peach Bottom reactors[a]

Reactor [type, net MW(e)] and waste type	Projected LLW class	Disposal volume (m^3)
Peach Bottom, Unit 2 [BWR, 1065]		
LLW	A	23,980
LLW	C	504
LLW	GTCC	169
Subtotal		24,653
Peach Bottom, Unit 3 [BWR, 1065]		
LLW	A	24,913
LLW	C	504
LLW	GTCC	169
Subtotal		25,586
Total		50,239

[a]Peach Bottom data were adapted from ref. 40.

Table 7.19. Characteristics of radioactive wastes associated with decommissioning the Pathfinder reactor[a]

Reactor component(s)/waste	Volume[b] (m^3)	Mass (t)	Activity (Ci)
Reactor vessel[c]	113	280.5	560.92
Bioshield	78	179	0.26
Recirculation pumps and motors (3)	71	56	0.018
Contaminated concrete	50	40	0.065
Dry active waste[d]	567	635.5	0.557
Liquids	0	0	0
Asbestos	97[e]	17	0.0001
Total	976	1,208	561.82

[a]Based on ref. 41. All material is low-specific-activity LLW.

[b]These numbers represent the volume of radioactive waste shipped to processors; the final disposal volumes have not yet been determined.

[c]Includes reactor pressure vessel, internal components, control rod drive blades, gravel, grout, and routine shipping (Type A) packaging components.

[d]Includes piping, valves, conduit, cable, sand, wire, steel, shield blocks, grating, lights, filters, plastic, paper, and wood.

[e]This is the volume of asbestos removed during D&D. Later this material was reduced in volume to 20 m^3.

Table 7.20. Projected characteristics of wastes from Shoreham BWR decommissioning activities[a,b]

(All wastes are projected to be LLW Class A)

Reactor component(s)/waste	Burial volume (m^3)	Activity[c,d] (Ci)
Reactor pressure vessel (RPV) and internals	467	6.01E+2
Reactor recirculation system	170	2.45E-4
Control rod drive system	14[e]	3.00E-4
Residual heat removal system	428	4.30E-4
Core spray system	45	7.19E-4
Reactor water cleanup system	260	6.16E-4
Fuel pool cleanup system	71	7.86E-4
Condensate and demineralizer system	57	2.62E-5
Process sampling system	9	2.29E-5
Spent fuel rack and accessories	235	5.65E-4
Process and dry activated wastes	218	f
Demineralizer system and resins/filters	91	f
Liquid radwaste system	170	1.60E-4
Mirror insulation	11	f
Total	2,246	6.01E+2

[a]Based on the Shoreham Nuclear Power Station Decommissioning Plan (ref. 42).

[b]The 820-MW(e) Shoreham BWR underwent low-power tests until 1989, when the Long Island Lighting Company agreed to sell the plant to the state of New York for decommissioning. A total of 865 MW(e)-hours of (gross) electrical energy were generated during the low power tests.

[c]Activity levels are as of March-April 1990, except for the RPV and internals, which reflect levels as of July 1990.

[d]The isotopic composition of Shoreham's anticipated wastes is assumed to be represented by two radionuclides: ^{60}Co (comprising one-third of the total activity) and ^{55}Fe (comprising the remaining two-thirds of the total activity).

[e]Excludes control blades and control rod drives.

[f]Negligible.

Table 7.21. Projected volumes of wastes from Indian Point Unit 1 PWR decommissioning activities[a,b]

Reactor component(s)	Container (type and number)		
	LSA boxes	Cask liners	Total
Contaminated piping, valves, equipment, and concrete	1,269	0	1,269
Spent fuel racks	9	0	9
Reactor internals	7	13	20
Reactor vessel	52	0	52
Total containers	1,337	13	1,350
External volume (m^3) of each container (box or liner)	4.694	3.341	–
Total container volume (m^3)	6,275	43	6,318

[a]Based on ref. 43.
[b]The 265-MW(e) Indian Point Unit 1 PWR began operation in 1962 and generated about 1,440 MW(e)-years of (gross) electrical energy before it was shut down in 1974. The projections in this table pertain to wastes from the dismantlement of the reactor following a SAFSTOR period of about 35 years.

Table 7.22. Characteristics of wastes from decommissioning activities at the Cimarron Fuel Fabrication Facility[a]

Project area	Type of waste	Total waste removed from Cimarron through December 1991[b]		Projected waste volume remaining[c] (m^3)
		Volume (m^3)	Activity (Ci)	
Burial ground	LLW (LSA)[d]	1,833.10	5.37	0
Mixed-oxide fuel plant	TRU	255.89	10.87	0
	LLW (LSA)	463.88	3.25	0
Uranium fuel plant areas				
a. Uranium fuel plant	LLW (LSA)	2,158.62	3.63	500
b. Northfield area	LLW (LSA)	188.82	.12401	142
Liquid process waste evaporation ponds				
a. Mixed-oxide plant pond	LLW (LSA)	104.30	0.000009	0
b. Uranium plant pond	LLW (LSA)	183.73	0.23	0
Sanitary lagoons	LLW (LSA)	1,559.26	2.93	0
Project totals	TRU	255.89	10.87	0
	LLW (LSA)	6,491.71	15.53	642
Total waste		6,747.60	26.40	642

[a]Based on the information provided in ref. 44.
[b]The LLW inventories are included in the commercial disposal site inventories of Chapter 4.
[c]Decontamination work is scheduled to be completed during 1993. More than 95% of the estimated decontamination requirement has been completed.
[d]LSA = low-specific-activity waste.

ORNL PHOTO 6896-92

Photo 8.1. Retrieval of mixed low-level waste sludge from a Hanford Site solar evaporation basin. (Courtesy of Westinghouse Hanford Company, Richland, Washington, and the Hazardous Waste Remedial Actions Program, Oak Ridge, Tennessee.)

8. MIXED LOW-LEVEL WASTE

8.1 INTRODUCTION

This chapter reports estimated inventories and generation rates of mixed LLW from DOE site and commercial operations. Mixed LLW includes mixtures of low-level radioactive materials and (chemically and/or physically) hazardous wastes. Mixed high-level and TRU wastes are not included in this chapter but are included in the HLW and TRU waste inventories and projections of Chapters 2 and 3, respectively. This report does not consider the chemically hazardous features of mixed HLW or TRU wastes. Their dominating radioactive characteristics alone dictate the methods by which these materials need to be treated, handled, stored, and disposed. The radioactive components of mixed wastes are subject to the Atomic Energy Act (AEA), as amended,[1] which, for government sources, is administered by DOE, and, for commercial sources, by NRC (unless a state has obtained agreement state status). The hazardous components of all mixed wastes are subject to two federal statutes that are administered by the Environmental Protection Agency (EPA) (unless a state has obtained an authorization status): (1) the Resource Conservation and Recovery Act (RCRA), as amended,[2] and (2) the Toxic Substances Control Act (TSCA).[3] Thus, the treatment, handling, and disposal of mixed wastes are subject to the regulations of the EPA[4] and NRC (or the authorized and agreement states), or DOE. Table 8.1 (data from ref. 5) lists those states and territories designated by EPA as having mixed waste authorization.

In this report, mixed LLW is considered separately from the purely radioactive LLW discussed in Chapter 4. The information provided in the tables of this chapter is preliminary in nature and pertains only to hazardous wastes regulated by RCRA and polychlorinated biphenyls (PCBs) regulated by TSCA. Unless otherwise noted, the inventories and projections reported for mixed LLW are separate from those reported for radioactive LLW in Chapter 4. Inventories of mixed LLW presently stored at DOE sites are in the process of being thoroughly characterized. As a result, the waste at some sites could require reclassification, thereby causing significant changes in the inventories currently reported.

Typically, mixed LLW at DOE sites includes a variety of contaminated materials, including air filters, cleaning materials, engine oils and grease, paint residues, photographic materials, soils, building materials, and decommissioned plant equipment. To support the DOE Office of Environmental Restoration and Waste Management, the Hazardous Waste Remedial Actions Program (HAZWRAP) has developed the Waste Management Information System (WMIS), a data base of treatment, storage, and disposal (T/S/D) unit capabilities and waste stream characteristics at DOE sites. Presently, WMIS contains mixed waste and hazardous, polychlorinated biphenyl (PCB), and radioactive T/S/D unit capabilities and waste stream characterization information.

8.2 WASTE CHARACTERIZATION

Currently, generic characterization of mixed wastes is difficult for several reasons: (1) such wastes have different blends of hazardous (chemical and/or physical) and radioactive components that dictate precautionary measures, (2) several processes may be involved in generating these wastes, (3) various methods are used to prepare these wastes for storage, and (4) EPA has adopted new toxicity characterization leaching procedures. Representative data on the chemical and radionuclide compositions of mixed wastes will be reported as more detailed site information is available.

In this chapter, inventories and annual generation rates of mixed LLW are expressed in terms of physical and hazardous categories. Physical properties are classified in four categories: solid, liquid, gas, and sludge. Chemical properties are classified according to six categories defined by RCRA and TSCA.

8.3 DOE SITE INVENTORIES AND GENERATION RATES

Cumulative mass inventories and generation rates are reported in this chapter for most of the DOE sites listed in Table D.1 of Appendix D. The DOE site inventories and generation rates reported are based on information compiled and processed by HAZWRAP (ref. 6). The levels reported do not reflect any treatment that may take place before interim storage. Thus, some generation rates

may vary from current inventory additions. DOE site inventories and generation rates are given in both mass (kg) and volume (m^3) units. Until recently, many DOE sites tracked and reported their mixed waste streams in mass units. However, for disposal considerations, DOE is requiring these sites to report their mixed waste inventories and generation rates in units of disposal volume. A breakdown of DOE site mixed LLW inventories and generation rates by various physical categories is provided in Tables 8.2–8.5.

Chemically hazardous properties of mixed LLW are described by the following six categories of waste types: PCB, listed, ignitable, reactive, corrosive, and TCLP/EP (toxicity characteristic leaching procedure/extraction procedure) toxic. Table 8.6 (based on refs. 3, 7, and 8) gives a detailed description of the waste characteristics associated with each of the hazard categories. Tables 8.7 through 8.10 report DOE site mixed LLW inventories and generation rates for these categories. The columns in Tables 8.7 through 8.10 are ordered according to the potential hazard presented to humans and the environment, with PCBs accounting for the greatest hazard and TCLP/EP toxic the least hazard. This ordering also reflects considerations given to waste handling. The methodology used in preparing Tables 8.7 through 8.10 assumes that if a waste stream composition falls into more than one category, then its inventory and generation rates are included in the most severe category. (For example, a waste stream containing both PCBs and corrosives would be included in the PCB column.)

A breakdown of the mixed LLW volume inventory by site is graphically described in Fig. 8.1, and a breakdown of the volume generation level by site is shown in Fig. 8.2. The current total volume inventory of mixed LLW at DOE sites is about 101,400 m^3, most of which is located at ten sites (Fernald, ORNL, Paducah, Hanford, INEL, K-25, Portsmouth, Rocky Flats, SRS, and Y-12). During 1991, over 65,000 m^3 of mixed LLW was generated at DOE sites. Tables 8.11 and 8.12 report projected mass and volume generation rates, respectively, of mixed LLW at DOE sites. Data reported in these tables are based on information currently available from WMIS (ref. 6).

8.4 COMMERCIAL MIXED LOW-LEVEL WASTES

Recently, the NRC and EPA cosponsored a survey study to compile a national profile of the volumes, characteristics, and treatability of commercially generated mixed LLW. Such a profile was designed to provide: (1) states and compacts with information to assist in planning and developing adequate disposal capacity for low-level radioactive waste, including mixed waste, as mandated by the Low-Level Radioactive Waste Policy Amendments Act; (2) private developers with a clearer idea of the characteristics and volumes of mixed waste and the technical capability and capacity needed to treat this waste; and (3) a reliable national data base on the volumes, characteristics, and treatability of commercial mixed waste. In addition, the data were collected to provide a basis for possible federal actions that would effectively manage and regulate the treatment and disposal of mixed waste. Results from this investigation are documented in ref. 9 and summarized in this report.

The NRC/EPA study identified the types and volumes of mixed LLW generated from five groups of facilities: nuclear utilities, medical facilities, academic institutions, industrial facilities, and NRC-licensed government facilities. The study selected a random sample of 1,323 facilities out of a total target population of 2,936 facilities. Data from 1,016 completed mixed waste survey questionnaires (77% response rate) received and the use of appropriate weighting factors indicate that approximately 3,950 m^3 of low-level radioactive mixed waste was generated in the United States in 1990 of which 72% was liquid scintillation fluids.

The study divided the low-level radioactive mixed waste into several hazardous stream categories, including the following:

- Liquid scintillation fluids from laboratory counting activities.
- Waste oil from various pumps, equipment, and maintenance activities.
- Chlorinated or fluorinated organics and chlorinated fluorocarbons, including sludges and contaminated filters from dry cleaning, refrigeration, degreasing, and decontamination operations. Chloroform and a number of pesticides are also included.
- Other organics, including miscellaneous solvents, reagents, expired products, and other organic compounds (or materials like rags, wipes, etc., contaminated with such) from research and manufacturing activities, experimental procedures, and laboratory and process equipment cleaning.
- Lead wastes, including lead shielding and lead solutions for research and industrial facilities.
- Mercury wastes, including equipment and debris contaminated with mercury.
- Chromate wastes, including chromium-contaminated solutions for research maintenance and waste treatment (ion exchange) operations.
- Cadmium wastes from decontamination activities.
- Aqueous corrosive wastes, including inorganic acids or, in some cases, bases from cleanup and decontamination activities.
- Other hazardous materials, including materials either not readily assignable to any one of the above categories or containing a number of different hazardous materials.

Summaries of estimated generation rate, amount in storage, and amount treated for each of the five facility

categories and each of the hazardous stream categories are shown in Tables 8.13 and 8.14, respectively (data from ref. 9). Upper and lower bounds were also set on the volume of mixed waste that is untreatable under current technologies by making the simplifying assumption that liquid scintillation fluids, oil, nonhalogenated organics, and corrosive wastes are treatable. Deducting their contributions from the estimated total mixed waste generation rate leaves residues of about 524 m^3. This upper bound for untreatable mixed waste is approximately 13% of the estimated 1990 national generation rate of 3,950 m^3. However, it was noted that the capacity to treat all the so-called treatable mixed waste may not be available.

8.5 REFERENCES

1. U.S. Congress, Atomic Energy Act of 1954, Pub. L. 83-703, Aug. 15, 1954.

2. U.S. Congress, Resource Conservation and Recovery Act of 1976, Pub. L. 94-580, Oct. 21, 1976, as amended by the Hazardous and Solid Waste Amendments Acts of 1984, Pub. L. 98-616, Nov. 9, 1984.

3. U.S. Congress, Toxic Substances Control Act of 1976, Pub. L. 94-469, Oct. 11, 1976.

4. U.S. Environmental Protection Agency, "Identification and Listing of Hazardous Waste," Code of Federal Regulations, 40 CFR Parts 260–271 (1986).

5. Betty Shackleford, U.S. Department of Energy, Office of Program Support, Office of Waste Operations, Washington, D.C., facsimile to S. N. Storch, Oak Ridge National Laboratory, Oak Ridge, Tennessee, dated Mar. 15, 1992, containing updated EPA mixed waste authorization status for states and U.S. territories as of Dec. 31, 1991.

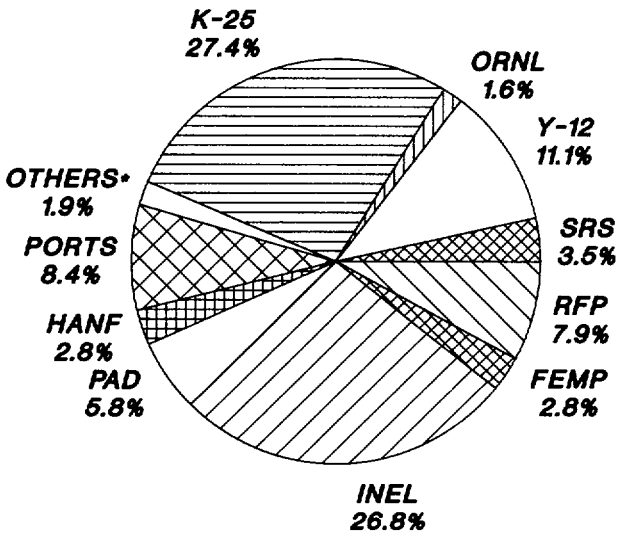
6. U.S. Department of Energy, Waste Management Information System (WMIS), DOE site mixed LLW inventory and projection data summaries prepared by the Hazardous Waste Remedial Actions Program (HAZWRAP), submitted to the Integrated Data Base Program, May–September 1992.

7. S. M. DePaoli, A. L. Rivera, and B. M. Eisenhower, Hazardous and Mixed Waste Generation at the DOE/ORO Installations Operated by Martin Marietta Energy Systems, Inc., During Calendar Years 1987 and 1988, K/ESH-2, Oak Ridge, Tennessee (September 1990).

8. U.S. Environmental Protection Agency, Code of Federal Regulations, 40 CFR Parts 702-799 (1988).

9. National Profile on Commercially Generated Low-Level Radioactive Mixed Waste — Technical Letter Report for Tasks Five and Six, prepared by Oak Ridge National Laboratory, Oak Ridge, Tennessee, for U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency, FIN L-1647-0, June 19, 1992.

ORNL DWG 92-6862



SITE	CUBIC METERS
FEMP	2.824E+03
HANF	2.831E+03
INEL	2.716E+04
K-25	2.778E+04
ORNL	1.598E+03
PAD	5.941E+03
PORTS	8.488E+03
RFP	7.972E+03
SRS	3.568E+03
Y-12	1.131E+04
OTHERS*	1.918E+03
TOTAL	1.014E+05

*Includes contributions from 28 sites.

Fig. 8.1. Total volume inventory of DOE mixed LLW through 1991.

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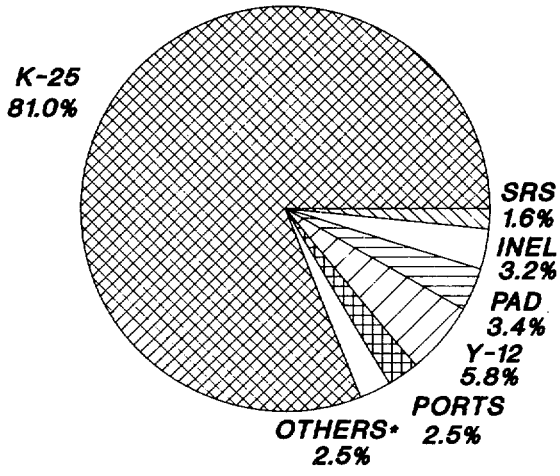

SITE	CUBIC METERS
INEL	2.093E+03
K-25	5.353E+04
PAD	2.212E+03
PORTS	1.679E+03
SRS	1.072E+03
Y-12	3.803E+03
OTHERS*	1.661E+03
TOTAL	6.605E+04

*Includes contributions from 32 sites.

Fig. 8.2. Volume generation of DOE mixed LLW during 1991.

Table 8.1. States and territories with EPA mixed waste authorization[a]

State/territory	Effective date	State/territory	Effective date
Arkansas	05/29/90	Nebraska	12/03/88
Colorado	11/07/86	New Mexico	07/25/90
Connecticut	12/31/90	New York	05/07/90
Florida	02/12/91	North Carolina	11/21/89
Georgia	09/26/88	North Dakota	08/24/90
Guam	10/10/89	Ohio	06/30/89
Idaho	04/09/90	Oklahoma	11/27/90
Illinois	04/30/90	Oregon	05/29/90
Indiana	09/30/91	South Carolina	09/13/87
Kansas	06/25/90	South Dakota	06/17/91
Kentucky	12/19/88	Tennessee	08/11/87
Louisiana	10/26/91	Texas	03/15/90
Michigan	12/26/89	Washington	11/23/87
Minnesota	06/23/89	Utah	03/07/89
Mississippi	05/28/91		
		(Total = 29 states/territories)	

[a]Based on ref. 5. Information as of December 31, 1991.

Table 8.2. Cumulative mass (kg) inventories of DOE site mixed LLW, by physical category, through 1991[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
AMES	470	0	0	0	470
ANL-E	25,273	47,454	0	32,500	105,227
ANL-W	17,927	177	0	0	18,104
BNL[d]	0	14,930	0	0	14,930
FEMP	80,693,584	401,535	0	1,708,126	82,803,245
FNAL	740	0	0	0	740
HANF	2,728,784	110,200	0	0	2,838,984
INEL	23,267,153	140,738	0	2,613,386	26,021,277
ITRI	0	640	0	0	640
K-25[e]	3,949,958[f]	1,002,576	1,222	36,213,808	41,167,564
KCP	4,260	0	0	0	4,260
LANL	171,382	37,386	0	224,160	432,928
LBL	4,624	8,528	0	0	13,152
LLNL	53,001	134,300	0	0	187,301
MOUND	5,169	45,003	0	0	50,172
NR sites[g]	153	0	0	0	153
NTS	130,500	50,000	0	0	180,500
ORISE	0	0	0	0	0
ORNL	5,500	1,206,135	0	99,182	1,310,817
PAD	1,885,479	246,275	0	2,938,938	5,070,692
PANT	7,110	2,587	0	0	9,697
Pinellas	0	0	0	0	0
PORTS	3,696,300	445,320	0	2,962,780	7,104,400
PPPL	0	76	0	0	76
RAP sites[h]	222,372	55,999	0	9,199	287,570
RFP	8,117,969	23,260	0	363,559	8,504,788
RMI	60,059	5,332	0	5,192	70,583
SLAC	0	0	0	0	0
SNLA[d]	281,744	1,000	0	0	282,744
SNLL	45	321	0	0	366
SRS	206,830	2,449,680	0	16,253	2,672,763
WVDP	16,656	572	0	0	17,228
Y-12	6,212,780	123,400	0	951,850	7,288,030
Total	131,765,822	6,553,424	1,222	48,138,933	186,459,401

[a]Based on ref. 6. Materials may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Stored in cylinders.

[d]Updated information for 1991 was not available from this site.

[e]Inventories reported include only wastes generated at K-25.

[f]Includes 3,635,908 kg of mixed PCB waste stored at K-25.

[g]Includes contributions from Bettis (BAPL) and NRF (INEL).

[h]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.3. Cumulative volume (m^3) inventories of DOE site mixed LLW, by physical category, through 1991[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
AMES	0.10	0	0	0	0.10
ANL-E	5.80	46.40	0	41.00	93.20
ANL-W	8.85	0.21	0	0	9.06
BNL[d]	0	14.93	0	0	14.93
FEMP	1,382.09	337.31	0	1,105.08	2,824.48
FNAL	0.18	0	0	0	0.18
HANF	2,720.89	110.20	0	0	2,831.09
INEL	24,010.30	393.47	0	2,742.68	27,146.45
ITRI	0	1.20	0	0	1.20
K-25[e]	2,633.31[f]	1,002.34	2.44	24,142.54	27,780.63
KCP	5.44	0	0	0	5.44
LANL	129.52	65.89	0	239.90	435.31
LBL	3.40	11.03	0	0	14.43
LLNL	35.33	134.33	0	0	169.66
MOUND	7.37	65.22	0	0	72.59
NR sites[g]	0.28	0	0	0	0.28
NTS	87.00	50.00	0	0	137.00
ORISE	0	0	0	0	0
ORNL	6.11	1,214.20	0	377.36	1,597.67
PAD	3,366.04	367.02	0	2,208.10	5,941.16
PANT	19.40	3.95	0	0	23.35
Pinellas	0	0	0	0	0
PORTS	3,913.54	483.43	0	4,090.68	8,487.65
PPPL	0	0.07	0	0	0.07
RAP sites[h]	151.09	270.57	0	8.38	430.04
RFP	7,353.30	132.71	0	486.27	7,972.28
RMI	72.93	6.63	0	7.15	86.71
SLAC	0	0	0	0	0
SNLA[d]	411.10	1.00	0	0	412.10
SNLL	0.22	0.63	0	0	0.85
SRS	542.34	3,010.13	0	15.40	3,567.87
WVDP	11.12	0.57	0	0	11.69
Y-12	3,853.70	123.40	0	7,330.70	11,307.80
Total	50,730.75	7,846.84	2.44	42,795.24	101,375.27

[a]Based on ref. 6. Materials may be in interim storage awaiting treatment.
[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.
[c]Stored in cylinders.
[d]Updated information for 1991 was not available from this site.
[e]Inventories reported include only wastes generated at K-25.
[f]Includes mixed PCB waste stored at K-25.
[g]Includes contributions from Bettis (BAPL) and NRF (INEL).
[h]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.4. Mass generation rates (kg/year) of DOE site mixed LLW, by physical category, for 1991[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
AMES	20	0	0	0	20
ANL-E	86	10,658	0	490	11,234
ANL-W	213	11	0	41	265
BNL[d]	0	1,166	0	0	1,166
FEMP	0	0	0	0	0
FNAL	679	32	0	0	711
HANF	603,204	4,960	0	0	608,164
INEL	21,700	2,543,374	0	684	2,565,758
ITRI	0	750	0	0	750
K-25[e]	124,997	55,465,003[f]	61	187,927	55,777,988
KCP	136	0	0	0	136
LANL	49,005	4,263	0	52,100	105,368
LBL	4,116	4,404	0	0	8,520
LLNL	12,174	59,035	215	7,366	78,790
MOUND	100	0	0	0	100
NR sites[g]	2,506	1,668	0	0	4,174
NTS	45,600	18,000	0	0	63,600
ORISE	0	110	0	0	110
ORNL	338	15,614	0	5,072	21,024
PAD	210,996	129,774	0	2,098,332	2,439,102
PANT	66,559	0	0	0	66,559
Pinellas	0	0	0	0	0
PORTS	1,104,656	117,694	0	34,900	1,257,250
PPPL	0	100	0	0	100
RAP sites[h]	15,048	11,635	0	10,186	36,869
RFP	621,483	1,136	0	7,839	630,458
RMI	46,558	623	0	493	47,674
SLAC	0	0	0	0	0
SNLA[d]	0	0	0	0	0
SNLL	0	161	0	0	161
SRS	22,519	1,043,954	0	0	1,066,473
WVDP	2,646	117	0	0	2,763
Y-12	122,403	3,134,100	0	545,000	3,801,503
Total	3,077,742	62,568,342	276	2,950,430	68,596,790

[a]Based on ref. 6. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Stored in cylinders.

[d]Updated information for 1991 was not available from this site.

[e]Rates reported include only wastes generated at K-25.

[f]Includes 901,565 kg of mixed PCB waste at K-25. Also includes approximately 45,000,000 kg of water from the TSCA Incinerator and 8,420,000 kg of hydrogen softener blowdown from the steam plant, which were both treated at the Central Neutralization Facility.

[g]Includes contributions from Bettis (BAPL) and NRF (INEL).

[h]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.5. Volume generation rates (m^3/year) of DOE site mixed LLW, by physical category, for 1991[a,b]

Site	Solid	Liquid	Gas[c]	Sludge	Total
AMES	0	0	0	0	0
ANL-E	0.01	9.53	0	0.40	9.94
ANL-W	1.02	0.01	0	0.02	1.05
BNL[d]	0	0.99	0	0	0.99
FEMP	0	0	0	0	0
FNAL	0.24	0.02	0	0	0.26
HANF	603.20	4.96	0	0	608.16
INEL	46.24	2,046.88	0	0.21	2,093.33
ITRI	0	1.50	0	0	1.50
K-25[e]	83.33	53,286.97[f]	0.12	155.69	53,526.11
KCP	0.15	0	0	0	0.15
LANL	48.10	10.10	0	54.90	113.10
LBL	2.60	5.91	0	0	8.51
LLNL	12.18	59.05	0.22	7.35	78.80
MOUND	0.14	0	0	0	0.14
NR sites[g]	27.56	2.09	0	0	29.65
NTS	30.40	18.00	0	0	48.40
ORISE	0	0.11	0	0	0.11
ORNL	0.33	15.94	0	5.14	21.41
PAD	477.95	149.76	0	1,584.13	2,211.84
PANT	82.40	0	0	0	82.40
Pinellas	0	0	0	0	0
PORTS	1,371.40	267.93	0	39.30	1,678.63
PPPL	0	0.10	0	0	0.10
RAP sites[h]	10.07	13.37	0	8.49	31.93
RFP	554.62	1.46	0	10.08	566.16
RMI	54.37	0.88	0	0.88	56.13
SLAC	0	0	0	0	0
SNLA[d]	0	0	0	0	0
SNLL	0	0.32	0	0	0.32
SRS	27.93	1,044.47	0	0	1,072.40
WVDP	1.76	0.11	0	0	1.87
Y-12	109.12	3,134.10	0	560	3,803.22
Total	3,545.12	60,074.56	0.34	2,426.59	66,046.61

[a]Based on ref. 6. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Stored in cylinders.

[d]Updated information for 1991 was not available from this site.

[e]Rates reported include only wastes generated at K-25.

[f]Includes contributions from mixed PCB waste, water from the TSCA Incinerator, and hydrogen softener blowdown from the steam plant. The incinerator water and hydrogen softener blowdown were treated at the Central Neutralization Facility.

[g]Includes contributions from Bettis (BAPL) and NRF (INEL).

[h]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.6. Hazard categories used in this report for characterizing DOE site mixed LLW[a]

Waste category	EPA code(s)	Description
PCB	(none)	PCB wastes[b] contain any form of polychlorinated biphenyl (PCB)-containing wastes (liquid, solid, equipment, etc.)
Listed	F001-F015 F006-F028 P001-P123 U001-U359	A waste is regarded as listed if it is characterized by EPA as hazardous and published in 40 CFR Part 261. Examples: spent solvents (F001-F015), spent sludges (F006-F028), discarded commercial chemicals (P001-P123 and U001-U359), poisons, regulated medical wastes, and combustibles (materials that have a flash point[c] above 60°C)
Ignitable	D001	A waste exhibits ignitability if the waste has a flash point under 60°C, or if, as a solid, it is capable of causing fire through friction at standard temperature and pressure (see 40 CFR Part 261.21). Examples: acetone, toluene, and alcohols
Reactive	D003	A waste exhibits reactivity if it is normally unstable, reacts violently with water, is capable of detonation, or generates toxic gases under certain conditions (see 40 CFR Part 261.23). Examples: poisons and carcinogens
Corrosive	D002	A waste exhibits corrosivity if the pH is <2 or >12.5, or if it corrodes steel at a specified rate (see 40 CFR Part 261.22). Examples: acids, bases, and crystalline solids (e.g., sodium hydroxide)
TCLP/EP toxic	D004-D043	A waste exhibits this toxicity if the leachate contains certain constituents (such as arsenic, lead, mercury, and silver) at concentrations equal to or higher than those given in 40 CFR Part 261.24

[a]Adapted from ref. 7.

[b]PCB wastes with PCB content ≥50 ppm are regulated by the Toxic Substances Control Act (TSCA) (ref. 3) under 40 CFR Parts 702-799 (ref. 8).

[c]The flash point is the lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air.

Table 8.7. Cumulative mass (kg) inventories of DOE site mixed LLW, by hazard category, through 1991[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
AMES	0	0	0	0	0	470	470
ANL-E	0	46,974	0	0	480	57,773	105,227
ANL-W	0	1,101	5,891	0	0	11,112	18,104
BNL[c]	0	14,930	0	0	0	0	14,930
FEMP	0	79,417,517	254,602	0	1,410,000	1,721,126	82,803,245
FNAL	152	0	0	0	0	588	740
HANF[d]	42,910	1,862,824	748,335	132,540	12,340	40,035	2,838,984
INEL	2,315,348	20,797,770	1,965,615	0	3,530	939,014	26,021,277
ITRI	0	640	0	0	0	0	640
K-25[e]	3,635,908	36,408,948	122,067	1	203,141	797,499	41,167,564
KCP	0	2,346	0	0	0	1,914	4,260
LANL	0	264,890	6,000	100	6,294	155,644	432,928
LBL	363	7,591	3,445	0	937	816	13,152
LLNL	120	181,759	600	0	4,822	0	187,301
MOUND	6,315	38,686	2	0	0	5,169	50,172
NR sites[f]	0	0	0	0	0	153	153
NTS	0	131,000	0	0	0	49,500	180,500
ORISE	0	0	0	0	0	0	0
ORNL	4,441	67,032	51,750	0	1,088,502	99,092	1,310,817
PAD	4,932,907	16,391	17,936	0	42,162	61,296	5,070,692
PANT	0	9,697	0	0	0	0	9,697
Pinellas	0	0	0	0	0	0	0
PORTS	6,078,400	761,222	5,000	0	33,328	226,450	7,104,400
PPPL	0	0	76	0	0	0	76
RAP sites[g]	112,779	64,464	10,064	9,079	649	90,535	287,570
RFP	3,944	8,479,411	984	96	0	20,353	8,504,788
RMI	0	5,984	0	0	0	64,599	70,583
SLAC	0	0	0	0	0	0	0
SNLA[c]	10,000	140,500	0	102,900	0	29,344	282,744
SNLL	0	321	0	0	0	45	366
SRS	0	2,418,365	130	79	96,800	157,389	2,672,763
WVDP	2,614	34	120	0	409	14,051	17,228
Y-12	5,289,512	1,718,686	0	0	0	279,832	7,288,030
Total	22,435,713	152,859,083	3,192,617	244,795	2,903,394	4,823,799	186,459,401

[a]Based on ref. 6. Material may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Updated information for 1991 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Inventories reported include only wastes generated at K-25.

[f]Includes contributions from Bettis (BAPL) and NRF (INEL).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.8. Cumulative volume (m^3) inventories of DOE site mixed LLW, by hazard category, through 1991[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
AMES	0	0	0	0	0	0.10	0.10
ANL-E	0	45.80	0	0	0.60	46.80	93.20
ANL-W	0	0.74	6.41	0	0	1.91	9.06
BNL[c]	0	14.93	0	0	0	0	14.93
FEMP	0	587.26	98.53	0	940.00	1,198.69	2,824.48
FNAL	0.12	0	0	0	0	0.06	0.18
HANF[d]	42.91	1,855.26	748.17	132.54	12.34	39.87	2,831.09
INEL	2,429.55	22,060.77	2,062.59	0	3.61	589.93	27,146.45
ITRI	0	1.20	0	0	0	0	1.20
K-25	3,635.91[e]	23,349.99	78.28	<<1	204.99	511.46	27,780.63
KCP	0	2.82	0	0	0	2.62	5.44
LANL	0	311.74	12.48	0.11	7.88	103.10	435.31
LBL	0.40	10.03	2.60	0	1.00	0.40	14.43
LLNL	0.11	165.82	.40	0	3.33	0	169.66
MOUND	9.14	56.08	0	0	0	7.37	72.59
NR sites[f]	0	0	0	0	0	0.28	0.28
NTS	0	104.00	0	0	0	33.00	137.00
ORISE	0	0	0	0	0	0	0
ORNL	4.47	75.04	51.79	0	1,088.51	377.86	1,597.67
PAD	4,836.69	30.41	21.88	0	73.16	979.02	5,941.16
PANT	0	23.35	0	0	0	0	23.35
Pinellas	0	0	0	0	0	0	0
PORTS	7,388.04	771.68	5.00	0	36.73	286.20	8,487.65
PPPL	0	0	0.07	0	0	0	0.07
RAP sites[g]	100.62	35.94	14.33	6.03	0.63	272.49	430.04
RFP	17.43	7,912.43	1.89	0.42	0	40.11	7,972.28
RMI	0	9.72	0	0	0	76.99	86.71
SLAC	0	0	0	0	0	0	0
SNLA[c]	35.00	94.00	0	268.30	0	14.80	412.10
SNLL	0	0.63	0	0	0	0.22	0.85
SRS	0	3,173.24	0.14	0.82	96.70	296.97	3,567.87
WVDP	1.74	0.03	0.12	0	0.41	9.39	11.69
Y-12	3,323.80	7,809.20	0	0	0	174.80	11,307.80
Total	21,825.93	68,502.11	3,104.68	408.22	2,469.89	5,064.44	101,375.27

[a]Based on ref. 6. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Updated information for 1991 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Inventories reported include only wastes generated at K-25.

[f]Includes contributions from Bettis (BAPL) and NRF (INEL).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.9. Mass generation rates (kg/year) of DOE site mixed LLW, by hazard category, for 1991[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
AMES	0	0	0	0	0	20	20
ANL-E	0	9,704	0	0	954	576	11,234
ANL-W	0	123	0	0	11	131	265
BNL[c]	0	1,166	0	0	0	0	1,166
FEMP	0	0	0	0	0	0	0
FNAL	90	0	32	0	0	589	711
HANF[d]	0	561,484	12,160	15,430	610	18,480	608,164
INEL	0	2,540,754	186	0	0	24,818	2,565,758
ITRI	0	750	0	0	0	0	750
K-25[e]	901,565	45,793,215	55,316	2	8,498,657	529,233	55,777,988
KCP	0	0	0	0	0	136	136
LANL	0	59,863	0	0	500	45,005	105,368
LBL	0	3,804	3,300	0	600	816	8,520
LLNL	0	78,162	311	0	317	0	78,790
MOUND	0	0	0	0	0	100	100
NR sites[f]	0	2,313	0	0	0	1,861	4,174
NTS	0	45,000	0	0	0	18,600	63,600
ORISE	0	110	0	0	0	0	110
ORNL	4,395	10,049	2,094	1	135	4,350	21,024
PAD	2,391,287	8,694	12,204	0	2,156	24,761	2,439,102
PANT	0	66,559	0	0	0	0	66,559
Pinellas	0	0	0	0	0	0	0
PORTS	625,671	600,863	2,880	0	1,600	26,236	1,257,250
PPPL	0	0	100	0	0	0	100
RAP sites[g]	7,703	99	1,415	244	0	27,408	36,869
RFP	0	628,457	0	0	0	2,001	630,458
RMI	0	745	0	0	0	46,929	47,674
SLAC	0	0	0	0	0	0	0
SNLA[c]	0	0	0	0	0	0	0
SNLL	0	161	0	0	0	0	161
SRS	0	5,099	0	0	1,043,200	18,174	1,066,473
WVDP	2,615	20	42	0	49	37	2,763
Y-12	45,000	622,723	30	0	3,120,000	13,750	3,801,503
Total	3,978,326	51,039,917	90,070	15,677	12,668,789	804,011	68,596,790

[a]Based on ref. 6. Values do not reflect any treatment that may, or will, occur prior to interim storage.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate masses when the site did not report mass data.

[c]Updated information for 1991 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Rates reported include only wastes generated at K-25.

[f]Includes contributions from Bettis (BAPL) and NRF (INEL).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.10. Volume generation rates (m^3/year) of DOE site mixed LLW, by hazard category, for 1991[a,b]

Site	PCB	Listed	Ignitable	Reactive	Corrosive	TCLP/EP toxic	Total
AMES	0	0	0	0	0	0	0
ANL-E	0	9.00	0	0	0.53	0.41	9.94
ANL-W	0	0.95	0	0	0.01	0.09	1.05
BNL[c]	0	0.99	0	0	0	0	0.99
FEMP	0	0	0	0	0	0	0
FNAL	0.16	0	0.02	0	0	0.08	0.26
HANF[d]	0	561.48	12.16	15.43	0.61	18.48	608.16
INEL	0	2,032.52	0.42	0	0	60.39	2,093.33
ITRI	0	1.50	0	0	0	0	1.50
K-25[e]	972.62	45,748.11	55.24	<<.01	6,373.99	376.15	53,526.11
KCP	0	0	0	0	0	0.15	0.15
LANL	0	72.00	0	0	1.00	40.10	113.10
LBL	0	5.31	2.20	0	0.60	0.40	8.51
LLNL	0	78.17	.32	0	0.31	0	78.80
MOUND	0	0	0	0	0	0.14	0.14
NR sites[f]	0	6.70	0	0	0	22.95	29.65
NTS	0	36.00	0	0	0	12.40	48.40
ORISE	0	0.11	0	0	0	0	0.11
ORNL	4.60	10.13	2.13	0	0.13	4.42	21.41
PAD	2,143.88	17.97	19.32	0	5.50	25.17	2,211.84
PANT	0	82.40	0	0	0	0	82.40
Pinellas	0	0	0	0	0	0	0
PORTS	908.00	734.73	2.70	0	1.50	31.70	1,678.63
PPPL	0	0	0.10	0	0	0	0.10
RAP sites[g]	7.54	0.11	2.14	0.66	0	21.48	31.93
RFP	0	561.54	0	0	0	4.62	566.16
RMI	0	1.10	0	0	0	55.03	56.13
SLAC	0	0	0	0	0	0	0
SNLA[c]	0	0	0	0	0	0	0
SNLL	0	0.32	0	0	0	0	0.32
SRS	0	9.67	0	0	1,043.20	19.53	1,072.40
WVDP	1.75	0.02	0.04	0	0.04	0.02	1.87
Y-12	40.00	634.00	0.02	0	3,120	9.20	3,803.22
Total	4,078.55	50,604.83	96.81	16.09	10,547.42	702.91	66,046.61

[a]Based on ref. 6. Material may be in interim storage awaiting treatment.

[b]Densities of 1,000 kg/m^3 for liquids and 1,500 kg/m^3 for solids and sludges were assumed to calculate volumes when the site did not report volume data.

[c]Updated information for 1991 was not available from this site.

[d]Hanford applied a different hazardous ordering scheme for wastes with two or more chemical categories: listed (highest), ignitable, corrosive, TCLP/EP toxic, reactives and other, and PCB (lowest).

[e]Rates reported include only wastes generated at K-25.

[f]Includes contributions from Bettis (BAPL) and NRF (INEL).

[g]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

Table 8.11. Projected annual mixed LLW mass generation rates (kg/year) for various DOE sites[a]

Site	Calendar year(s)					
	1992	1993	1994	1995	1996	1997-2030[b]
AMES[c]	2,600	2,700	1,890	1,890	650	540
ANL-E	17,925	16,513	16,513	16,513	16,513	16,513
ANL-W[d]						
BNL[d]						
FEMP	750,000	1,500,000	2,000,000	2,500,000	e	e
FNAL	610	610	610	610	610	610
HANF[f]	7,200,820	1,100,660	1,840,960	1,857,900	1,544,290	2,648,690
INEL[g]	10,000,000	9,600,000	9,600,000	9,600,000	9,600,000	9,600,000
ITRI	0	0	0	0	0	0
K-25[e]						
KCP	90	90	90	90	90	0
LANL	50,000	50,000	50,000	50,000	50,000	50,000
LBL	3,964	3,964	3,964	3,964	3,964	3,964
LLNL	82,000	82,000	82,000	82,000	82,000	82,000
MOUND	1,900	1,700	1,500	1,500	1,500	1,500
NR sites[h]	19,618	2,080	1,280	1,180	980	864
NTS	0	0	0	0	0	0
ORISE	300	300	350	400	400	500
ORNL	13,000	12,500	12,000	12,000	12,000	12,000
PAD	680,884	1,413,095	1,046,990	1,046,990	1,046,990	1,046,990
PANT	4,558	5,014	5,514	6,067	6,674	48,183
Pinellas	0	0	0	0	0	0
PORTS	2,310,000	2,540,000	2,290,000	2,310,000	2,310,000	2,310,000
PPPL[i]	600	600	600	11,900	11,900	555[j]
RAP sites[k]	7,730	7,730	230	2,230	4,230	230
RFP[l]	6,720,000	70,349	70,349	70,349	70,349	70,349
RMI	730	d	d	d	d	d
SLAC	12	12	12	12	12	e
SNLA	23,000	23,500	23,500	23,500	23,500	23,500
SNLL	161	161	161	161	161	<155
SRS[i]	330,000	240,000	270,000	285,000	285,000	285,000
WVDP	1,000	m	m	m	m	m
Y-12	2,872,800	2,514,000	2,199,600	1,924,800	1,683,600	1,440,000
Total	31,094,302	19,187,578	19,518,113	19,809,056	16,755,413	17,642,143

[a]Based on ref. 6.

[b]Annual average for the period indicated.

[c]If a burial site at Ames is excavated in 1993, a potential generation of 80,000 kg/year could result.

[d]Information not reported by site.

[e]Information not available.

[f]Includes contribution from Hanford's receipt of waste in 1992 that is currently being stored by off-site generators.

[g]Projections for INEL do not include contributions from environmental restoration activities planned at the site over the next 30 years. More waste characterization analyses and studies are needed to predict how much mixed LLW will result from these activities.

[h]Includes contributions from Bettis (BAPL), Knolls (KAPL), and NRF (INEL).

[i]Mass generation rates for this site are based on an assumed density of 1,500 kg/m^3.

[j]Average for years 1997-2001. No projections available after 2001.

[k]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

[l]Projections for RFP assume completion of solar pond cleanout and the resumption of plant production by the end of 1992.

[m]Mixed LLW generation data for WVDP cannot be estimated until programmatic and process uncertainties have been resolved in the development of a formal environmental impact statement.

Table 8.12. Projected annual mixed LLW volume generation rates (m^3/year) for various DOE sites[a]

Site	Calendar year(s)					
	1992	1993	1994	1995	1996	1997-2030[b]
AMES[c]	4.8	5.0	3.5	3.5	1.2	1.0
ANL-E	18	17	17	17	17	17
ANL-W[d]						
BNL[d]						
FEMP	1,100	2,500	3,319	4,165	e	e
FNAL	0.13	0.13	0.13	0.13	0.13	0.13
HANF[f]	6,546.2	1,000.6	1,673.6	1,689.0	1,403.9	2,407.9
INEL[g]	10,400	10,000	10,000	10,000	10,000	10,000
ITRI	0	0	0	0	0	0
K-25[e]						
KCP	0.1	0.1	0.1	0.1	0.1	0
LANL	50	50	50	50	50	50
LBL	7.26	7.26	7.26	7.26	7.26	7.26
LLNL	88	88	88	88	88	88
MOUND	2.2	2.0	1.8	1.8	1.8	1.8
NR sites[h]	4.12	3.92	1.92	1.42	1.11	1.09
NTS	0	0	0	0	0	0
ORISE	0.30	0.30	0.35	0.40	0.40	0.50
ORNL	13.0	12.5	12.0	12.0	12.0	12.0
PAD	939	1,503	1,221	1,221	1,221	1,221
PANT	7.00	7.70	8.47	9.32	10.25	74.00
Pinellas	0	0	0	0	0	0
PORTS	7,000	7,700	6,800	7,000	7,000	7,000
PPPL	0.40	0.40	0.40	7.93	7.93	0.37[i]
RAP sites[j]	6.5	6.5	0.3	3.3	6.3	0.3
RFP[k]	10,154.4	614.4	614.4	614.4	614.4	614.4
RMI	1.11	d	d	d	d	d
SLAC	0.06	0.06	0.06	0.06	0.06	e
SNLA	147	150	150	150	150	150
SNLL	0.32	0.32	0.32	0.32	0.32	<0.22
SRS	220	160	180	190	190	190
WVDP	0.66	1	1	1	1	1
Y-12	2,394	2,095	1,833	1,604	1,403	<1,200
Total	39,104.56	25,924.19	25,982.61	26,835.94	22,186.16	23,036.97

[a]Based on ref. 6.

[b]Annual average for the period indicated.

[c]If a burial site at Ames is excavated in 1993, a potential generation of 50 m^3/year could result.

[d]Information not reported by site.

[e]Information not available.

[f]Includes contribution from Hanford's receipt of waste in 1992 that is currently being stored by off-site generators.

[g]Projections for INEL do not include contributions from environmental restoration activities planned at the site over the next 30 years. More waste characterization analyses and studies are needed to predict how much mixed LLW will result from these activities.

[h]Includes contributions from Bettis (BAPL), Knolls (KAPL), and NRF (INEL).

[i]Average for years 1997-2001. No projections available after 2001.

[j]Includes contributions from Battelle (BCLDP), Colonie (CISS), Grand Junction (GJPO), Santa Susana (SSFL), and Weldon Spring (WSSRAP).

[k]Projections for RFP assume completion of solar pond cleanout and the resumption of plant production by the end of 1992.

[l]Mixed LLW generation data for WVDP cannot be estimated until programmatic and process uncertainties have been resolved in the development of a formal environmental impact statement.

Table 8.13. National commercially generated mixed LLW profile volume summary, by facility category[a]

Facility category	Waste volume, m^3		
	Generated in 1990	Stored as of Dec. 31, 1990[b]	Treated in 1990[c]
Academic	820.7	154.3	1,581.8
Government	750.4	79.0	612.5
Industrial	1,428.0	1,197.2	1,115.1
Medical	563.6	63.1	466.3
Nuclear power plants	385.8	622.5	216.9
Total	3,948.5	2,116.1	3,992.6

[a]Based on ref. 9.
[b]This is not the amount of mixed waste requiring disposal. Some of this waste was being accumulated for treatment.
[c]Treated wastes may include mixed wastes generated in years prior to 1990.

Table 8.14. National commercially generated mixed LLW profile volume summary, by hazardous waste stream[a]

Hazardous stream	Waste volume, m^3		
	Generated in 1990	Stored as of Dec. 31, 1990[b]	Treated in 1990[c]
Organics			
Liquid scintillation fluids	2,837.2	363.4	3,371.8
Waste oil	148.9	178.1	139.4
Chlorinated organics	70.9	27.0	23.2
Fluorinated organics	0	3.5	0
Chlorinated fluorocarbons (CFCs)	113.2	254.7	3.7
Other organics	274.6	117.9	258.9
Total organics	3,444.8	944.6	3,797.0
Metals			
Lead	81.6	138.7	6.1
Mercury	12.5	81.1	1.5
Chromium	28.4	53.3	3.9
Cadmium	0.3	745.2	0.1
Total metals	122.8	1,018.3	11.6
Aqueous corrosives	80.4	12.2	2.6
Other hazardous materials	300.5	141.0	181.4
Total	3,948.5	2,116.1	3,992.6

[a]Based on ref. 9.
[b]This is not the amount of mixed waste requiring disposal. Some of this waste was being accumulated for treatment.
[c]Treated wastes may include mixed wastes generated in years prior to 1990.

APPENDIX A. MISCELLANEOUS RADIOACTIVE MATERIALS

APPENDIX A. MISCELLANEOUS RADIOACTIVE MATERIALS

A.1 INTRODUCTION

This appendix lists most of the remaining spent fuel (not reported in Chapter 1) and other waste materials that may possibly require repository disposal. Current inventories of these wastes are in storage at DOE and commercial sites, and additional inventories will be generated in the future. The miscellaneous materials included are (1) intact spent fuel elements or solids remaining after experimental testing and for which no reprocessing is planned; (2) damaged, irradiated fuel elements and debris; and (3) greater-than-Class-C low-level waste (GTCC LLW), defined as low-level waste generated by licensees of NRC or Agreement States that exceeds the radioactivity limits established in 10 CFR 61.55 for shallow-land disposal. Most of the GTCC LLW currently in inventory is held by licensees of NRC or Agreement States, but some is being stored temporarily by DOE as a convenience (DOE-held GTCC LLW). Data for the following materials are not included because they do not fit in these categories: defense HLW in the tank farms, commercial spent fuel at power reactors, and both the DOE production fuel and U.S. Navy fuel that are scheduled for reprocessing.

Other kinds of miscellaneous radioactive materials (MRM) that might be considered for inclusion in this appendix are special-case wastes, spent fuel disassembly hardware and nonfuel-bearing components, high-activity sources, and radionuclides from the decommissioning of nuclear weapons. These MRM are characterized as follows:

- Special-case wastes are primarily those wastes that have limited or no planned disposal alternatives. Other than the fuel and fuel debris mentioned above, the special-case wastes consist of (a) WIPP noncertifiable defense TRU waste; (b) DOE-held commercial LLW (see DOE Order 5820.2A[1]) that potentially may be designated as GTCC, under the definition given in 10 CFR 61.55, with their disposal justified by a site-specific performance assessment; and (c) low-level wastes that exceed site-specific performance assessment limits. The Radioactive Waste Technical Support Program, managed by EG&G Idaho, Inc., was asked to identify and quantify these special-case wastes.[2,3]

- Spent fuel disassembly hardware is the structural component left after irradiated fuel pins are removed from a fuel assembly, as in consolidation. It consists of end fittings; grid spacers; water rods (BWR, most recent design only); control rod guide tubes (PWR assemblies only); and various nuts, washers, and springs. Nonfuel-bearing components include fuel channels (BWR), control rods, fission chambers, neutron sources, and thimble plugs.[4]

- High-activity sources include sealed sources of ^{14}C, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, and ^{241}Am.

- Radionuclides from the decommissioning of nuclear weapons are primarily plutonium isotopes.

The map of Fig. A.1 shows the current locations of MRM, and Fig. A.2 compares the masses of MRM now stored at the various sites. As seen in Fig. A.3, most of the material is in the form of either intact fuel elements or damaged fuel elements, such as those removed from the TMI-Unit 2 reactor.

A.2 INVENTORIES AND PROJECTIONS

Table A.1 summarizes the current inventory of MRM, exclusive of commercially generated GTCC LLW that may also require repository disposal. Tables A.2 through A.9 describe the separate materials at each site in more detail. The data presented in Tables A.1 through A.9 (derived from refs. 5–15) will be useful in planning for final disposal of these materials in a repository. It should be noted that some quantities of the commercially generated spent fuels reported in Tables A.2–A.9 may already be covered in Chapter 1 of this report. The spent fuel inventories reported in Tables A.2–A.9 will be reviewed to clearly identify any possible overlaps between the inventories in these tables and those reported in Chapter 1.

Any spent fuel inventory overlaps identified from this investigation will be clarified in the 1993 Integrated Data Base document (Rev. 9).

Inventories of special radioactive materials stored at INEL are given in Table A.6. These include materials stored at the Idaho Chemical Processing Plant (ICPP) and the Naval Reactors Facility (NRF). The spent fuels that comprise these inventories are scheduled to be stored indefinitely.[10-11] If required, future special campaigns could reprocess many of these spent fuels.

Data for the unusual spent fuels now being stored at SRS are included in Table A.9. These materials are not presently regarded as reprocessible, due to the lack of defined reprocessing schemes or required facilities. Therefore, this fuel is considered to be in indefinite storage.[15]

Other waste materials that could possibly require geologic disposal include GTCC LLW from commercial sources (including that held by DOE) and DOE spent fuel no longer scheduled for reprocessing. A summary of commercial GTCC LLW volumes and activities reported by the EG&G study of ref. 16 is presented in Table A.10. The major features of this study are described in Chapter 4. The results presented in Table A.10 represent packaged inventories and projections of wastes generated during the period 1985–2035. Recently, DOE made the decision to phase out the reprocessing of spent nuclear fuel for the recovery of highly enriched uranium. Idaho National Engineering Laboratory and the Savannah River Site are preparing phase-out plans. Implications of this decision will be reflected in next year's IDB report. Table A.11 (data from refs. 17–21) gives a mass summary of DOE spent fuel no longer scheduled for reprocessing. The information reported in Table A.11 is based on preliminary surveys and will be revised in future editions of this report.

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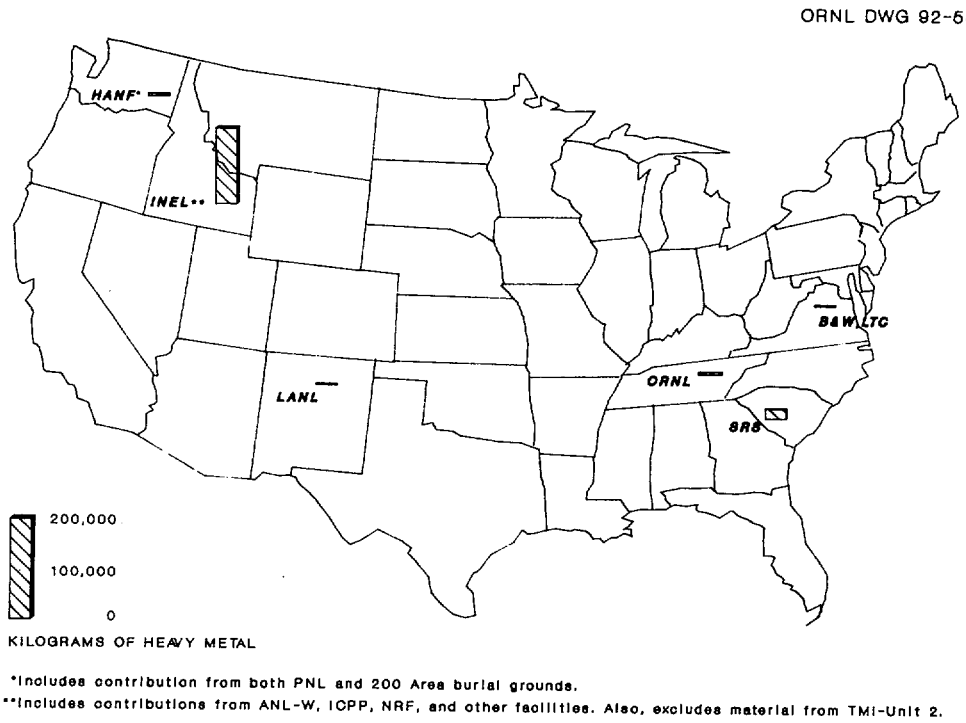

Fig. A.1. Locations and total masses of miscellaneous radioactive materials through 1991.

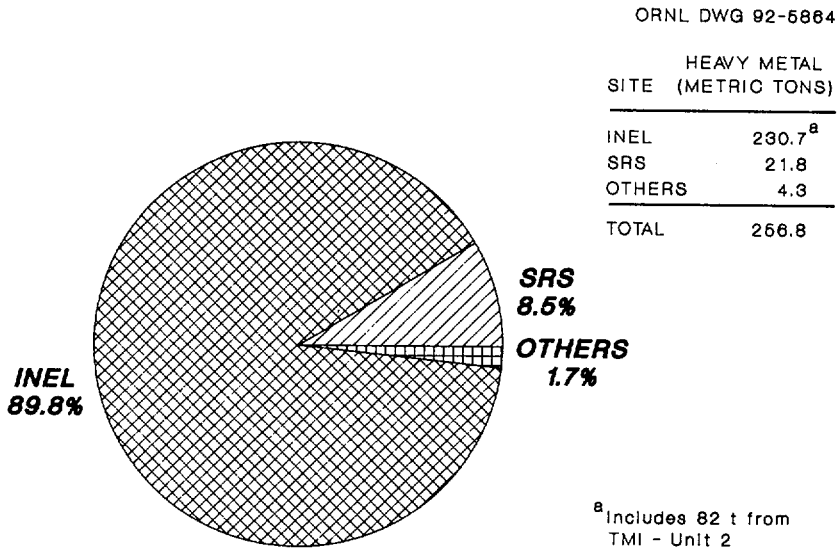

Fig. A.2. Mass and locations of miscellaneous radioactive materials as of December 31, 1991.

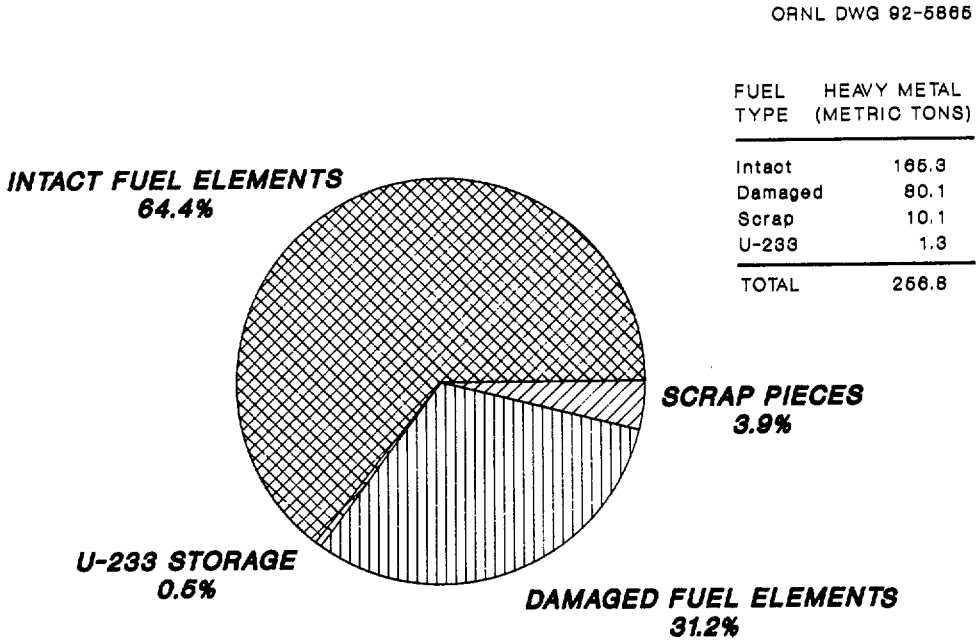

Fig. A.3. Types of miscellaneous radioactive materials in storage through 1991.

Table A.1. Inventory of miscellaneous radioactive materials that may require geologic disposal, as of December 31, 1991

Storage site and location	Total candidate materials (kg)	Uranium content, kg			Total plutonium content (kg)	Total thorium content (kg)
		Total	^{235}U	^{233}U[a]		
Reported potential miscellaneous materials inventory						
Argonne National Laboratory-West; Idaho Falls, ID	311.60	302.65	20.050		8.950	
Babcock & Wilcox, Lynchburg Technology Center; Lynchburg, VA	85.73	84.89	1.317		<0.833	
Battelle Pacific Northwest Laboratory; Richland, WA	2,347.9	2,311.9	21.6		29.3	6.7
Hanford 200-Area burial grounds; Richland, WA	326.73	279.49	76.06		47.24	
Idaho National Engineering Laboratory; Idaho Falls, ID[b]	148,711.81	81,334.46	1,958.59	962.46	273.75	67,103.6
Los Alamos National Laboratory; Los Alamos, NM	4.40	3.09	1.84	0.058	1.31	
Oak Ridge National Laboratory; Oak Ridge, TN	1,253.29	1,252.49	798.7	280.29	0.801	
Savannah River Site; Aiken, SC	21,783.74	13,092.33	762.46	31.16	43.21	8,648.2
Total reported	174,825.20	98,661.30	3,640.62	1,273.97	405.39	75,758.5
Estimated potential miscellaneous materials inventory						
Three Mile Island-Unit 2[c,d]	82,023	82,023	2,064.4			

[a]Some of the ^{233}U waste may be certifiable as TRU waste and would therefore be reported in Chapter 3 in the future.

[b]Many of the fuels at ICPP have a lower uranium enrichment than that of fuels normally processed. These fuels could be reprocessed in a special campaign, if required.

[c]Initial fuel loadings have been provided in order to estimate the potential miscellaneous materials inventory. See ref. 5.

[d]It is estimated that about 156 t of spent fuel and core debris has been removed from the TMI-Unit 2 reactor and transferred to INEL. See Table 7.10 in Chapter 7.

Table A.2. Miscellaneous radioactive materials stored at Argonne National Laboratory-West, as of December 31, 1991[a]

Source of material	Composition	Description[b]	U content, kg		Total Pu content (kg)
			Total	^{235}U	
Radioactive Waste and Scrap Facility[c]					
Basic research – ANL	Scrap	Stored in canister[d]	182.00	12.980	5.052
EBR-2 blanket subassembly	Scrap	Stored in canister[d]	104.80	0.230	0.180
LMFBR test fuel	Scrap	Stored in canister[d]	13.33	5.253	3.026
Postirradiation test on NUMEC LMFBR	Scrap	Stored in canister[d]	0.72	0.345	0.123
Sodium Loop Safety Facility	Scrap	Stored in canister[d]	1.80	1.242	0.569
Total			302.65	20.050	8.950

[a]See ref. 6.

[b]No information regarding the burnup of this scrap is available.

[c]Radioactive Scrap and Waste Facility is located approximately 0.5 miles north of ANL-W site.

[d]Canisters are retrievable and constructed of stainless steel with minimum dimensions of 8-in. OD and 5-ft length. The canister lid is gasketed and tightly screwed on, welded closed, or screwed into a canister fitted with pipe threads.

Table A.3. Miscellaneous radioactive materials stored at Babcock & Wilcox, Lynchburg Technology Center, as of December 31, 1991[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg		Total Pu content (kg)
				Total	^{235}U	
Arkansas I	UO_2, Zr-clad	Stored in four 4.25-in.-diam x 33-in. Al canisters	47,000	11.762	0.046	0.134
B&W Test Reactor	UO_2, Zr-clad	Stored in fourteen 4.25-in.-diam x 33-in. Al canisters	Unknown[c]	0.015	0.005	<0.0005
Consolidated Edison	UO_2, Zr-clad	Stored in a 4.25-in.-diam x 33-in. Al canister	29,523	10.849	0.060	0.088
Oconee I	UO_2, Zr-clad	Stored in twenty-six 4.25-in.-diam x 33-in. Al canisters	18,686	0.531	0.004	0.003
			24,080	2.159	0.028	0.017
			26,480	6.482	0.033	0.056
			31,160	4.275	0.041	0.037
			39,180	11.000	0.057	0.101
			50,000	8.517	0.030	0.094
Oconee I	UO_2-Gd_2O_3, Zr-clad	Stored in four 4.25-in.-diam x 33-in. Al canisters	15,000	7.911	0.103	0.048
Oconee II	UO_2, Zr-clad	Stored in seven 4.25-in.-diam x 33-in. Al canisters	27,500	10.711	0.105	0.095
			31,000	6.432	0.057	0.056
			36,000	1.999	0.015	0.020
TMI-Unit 2	UO_2 debris	Stored in a 4.25-in.-diam x 33-in. Al canister	Unknown[c]	0.047	0.0307	<0.0005
Various fuel scrap samples	UO_2, Zr-clad	Stored in a 4.25-in.-diam x 33-in. Al canister	Unknown[c]	2.202	0.702	<0.0005
Hot cell solid waste	Miscellaneous[d]	Stored in forty-four 80-gal drums, thirty-four 55-gal drums, and eighty-two 30-gal drums	-	[e]	[e]	<0.082[f]
Total				84.892	1.317	<0.833

[a]See ref. 7.
[b]Zr-clad = Zircaloy-clad.
[c]Currently in underground storage tubes.
[d]Miscellaneous materials from periodic hot cell cleanup.
[e]Negligible.
[f]Calculated assuming a contaminated level of <0.5 g of plutonium per drum.

Table A.4. Miscellaneous radioactive materials stored at Battelle Pacific Northwest Laboratory, as of December 31, 1991[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg		Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U		
Calvert Cliffs	UO_2, Zr-clad	0.440-in. diam x 147 in.					
		(stored as 175 intact rods, 1 cut rod[c])	30,000	370.5	2.6	5.3	
		(stored as 154 intact rods, 1 cut rod[c])	45,000	293.2	1.7	7.7	
Cooper	UO_2, Zr-clad	98 rods[c]	26,000	365.3	2.5	3.1	
Point Beach-1	UO_2, Zr-clad	Stored as three intact fuel assemblies, miscellaneous cut samples	32,000	1,163.6	10.3	10.6	6.7
H. B. Robinson	UO_2, Zr-clad	Stored as 19 cut fuel rod sections[c]	30,000	30.2	2.2	0.2	
Shippingport				3.9	0.1	0.1	
VBWR[d]	UO_2, Zr-clad	Twelve 3-ft fuel rod segments	20,000-30,000	11.1	0.1	0.7	
PNL Lot Numbers:							
ATM-5		Glass mix		0.1	e	<0.1	
ATM-6		Glass mix		0.1	e	<0.1	
Miscellaneous scrap and fuel	Cut pieces, scrap	Stored in hot cells		68.5	2.0	1.5	
Miscellaneous fuel	Cut pieces	Stored in hot cell	Unknown	5.4	0.1	0.1	
Total				2,311.9	21.6	29.3	6.7

[a]See ref. 8.
[b]Zr-clad = Zircaloy-clad.
[c]Stored in a hot cell.
[d]Vallecitos boiling-water reactor.
[e]Negligible.

Table A.5. Miscellaneous radioactive materials stored at the Hanford 200-Area burial grounds, as of December 31, 1991[a]

Source of material	Composition	Description[b]	U content, kg		Total Pu content (kg)
			Total	^{235}U	
EBR II (Experimental Breeder Reactor) From INEL	UO_2/PuO_2, SS-clad	Stored in four 30-in.-diam x 59.5-in. shielded carbon steel casks	45.53	7.64	3.60
From LANL	UO_2/PuO_2, SS-clad	Stored in twenty-four 30-in.-diam x 59.5-in. shielded carbon steel casks	78.34	51.42	28.45
From INEL and FFTF (Fast Flux Test Facility)	UO_2/PuO_2, SS-clad	Stored in five 30-in.-diam x 59.5-in. shielded carbon steel casks	34.65	7.55	9.81
Fast Critical Facility and SEFOR (Southwest Experimental Fast Oxide Reactor) from GE, Vallecitos, CA	UO_2/PuO_2	Stored in twenty-two 75.5-in. x 65.5-in. x 65.5-in. concrete casks	40.49	4.88	4.70
K reactor	Unknown	12 Am target elements stored in one 30-in.-diam x 69-in. Zircaloy container	0.024[c]	0.024	.074
LWRs (GETR,[d] Monticello Reactor, Quad Cities 1 Reactor, and Millstone Reactor)	UO_2 pellets	Stored in six 30-in.-diam x 59.5-in. shielded carbon steel casks	63.26	1.29	0.59
TRIGA (Training Reactor, Isotopes, General Atomic) from Oregon State University	Zr-U hydride (8 wt % U), Al-clad	3.6-cm diam x 72 cm fuel assemblies stored/buried in thirteen 55-gal concrete-filled drums, six to seven assemblies per drum	17.2	3.26	0.013
Total			279.49	76.06	47.24

[a]See ref. 9.
[b]No information regarding the burnup of this fuel is available.
[c]Enrichment of uranium not provided.
[d]General Electric (GE) Testing Reactor.

Table A.6. Miscellaneous radioactive materials stored at the Idaho National Engineering Laboratory, as of December 31, 1991[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Defense plus other government agency material stored at ICPP								
GCRE (Gas-Cooled Reactor Experiment)	UO_2-BeO, Hastelloy X clad	Two SS tubes, 2 in. x 44 in.	NA	0.984	0.918			
LWBR (Shippingport Light-Water Breeder Reactor)	Ceramic pellets, Zr-clad, Th blanket	47 units	NA	982.173	10.349	826.016	0.177	56,167.0
Misc. fuels and scrap	Scrap	Stored in 92 SS and Al cans	NA	42.16	31.18			
PWR Core 2 (Shippingport Pressurized-Water Reactor)	UO_2 pellets, Zr-clad	40 units	NA	521.613	395.969			
SM-1A (Stationary Media)	UO_2, SS-clad	Stored in 93 SS cans	Negligible	65.759	56.648			
TORY-IIA	UO_2-BeO cermet crushed to 0.25 in. x 0.06 in.	Stored in 147 Al cans 3.25 in. x 43 in.	0.002[c]	48.645	45.325			
TORY-IIC	UO_2-Y_2O_3-ZrO_2-BeO ceramic	Stored in three Al cans 2.68 in. x 52.5 in.	<1.5[c]	59.065	55.022			
Subtotal				1,720.399	595.561	826.016	0.177	56,167.0
DOE/Civilian Development Programs material stored at ICPP								
BORAX-V (Boiling Reactor Experiment No. 5)	UO_2, SS-clad	35 tube elements, 3.6 in. x 39 in. x 36 in.	NA	20.830	19.420			
EBR Scrap (Experimental Breeder Reactor)	Scrap	Four cans	NA	1.618	0.839			
Fermi 1 Blanket	U-Mo (97% U), sodium-bonded, SS-clad	Stored in 510 SS cans, 0.4-in. diam x 41 in. or 61 in.	<1[c]	34,165.000	120.000		6.522	

Table A.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at ICPP (continued)								
FSVR (Fort St. Vrain Reactor)	U-Th carbide and Th carbide, pyrolytic carbon-coated particles in graphite matrix	750 hexagonal graphite blocks 14.2 in. across flats x 31.2 in.	6,000-26,000	308.330	167.648	90.139	0.752	8,316.6
MURR (University of Missouri)	UAl_x, SS-clad	56 fuel elements, 4 in. x 4.5 in. x 32 in. in Al cans	NA	38.02	33.26			
PARKA (LANL critical assembly)	UC, ZrC	Graphite, ~3-in. diam x 54 in.	NA	147.98	137.84			
Pathfinder	UO_2-B_4C cermet pellets, SS-clad	411 assemblies in 17 SS cans; each can is 9-in. diam x 80 in.	<<1[c]	53.406	49.242			
Peach Bottom	U-Th carbide, pyrolytic carbon-coated particles in graphite matrix	1,603 graphite blocks 3.5-in. diam x 12 ft	>1[c]	332.420	223.540	46.310	0.970	2,620.0
Pulstar, State University of New York at Buffalo	UO_2 pellets in Zr-clad pins	Stored in 24 SS cans, 3 in. x 3 in. x 28.0 in.	<0.01	251.431	12.083		0.793	
TRIGA (Training Reactor, Isotopes, General Atomic)	Al- or SS-clad elements	845 units stored in 177 cans	Varies	160.974	34.680		0.029	
VBWR (Geneva) (Vallecitos Boiling-Water Reactor)	UO_2 and UO_2-TiO_2, SS-clad	142 rods stored in four 6-in.-diam x 36-in. Al cans	8[c]	12.383	2.606			
Subtotal				35,492.392	801.158	136.449	9.066	10,936.6

Table A.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
		DOE material stored at NRF[d]						
Shippingport PWR Core 1	UO_2 pellets, Zr-clad	Miscellaneous test specimens from blanket fuel assemblies	11,100	568	<0.5		3.4	
Shippingport PWR Core 2	UO_2 wafers, Zr-clad	Three modules and module sections from blanket fuel assemblies	14,273	1,028	2		8.9	
		One seed module		11.09	7.45			
Subtotal				1,607.09	9.45		12.3	
		DOE/Civilian Development Programs material stored at INEL (other than ICPP and NRF)						
CANDU (Canadian Deuterium Reactor)	UO_2 pellets, Zr-clad	8 pins	5,000	2.660	0.261			
Connecticut Yankee	UO_2, Zr-clad	1 assembly (200 pins)	NA	378.485	5.204		3.774	
Dresden	UO_2, Zr-clad	55 pins (depleted U)	NA	165.0	Unknown		1.064	
EMAD[e] (Engine Maintenance Assembly & Disassembly)	UO_2 pellets, Zr-clad	18 assemblies	25,000-30,000	7,831.273	58.103		65.255	
GAP CON (Gap Conductance)	UO_2 pellets, Zr-clad	20 pins	42-115	12.838	1.285			
GE (General Electric)	UO_2 pellets, Zr-clad	Pins	NA	18.644	0.394		0.071	
Halden Assy	UO_2 pellets, Zr-clad	5 pins	4,000	2.313	0.233		0.005	
Halden 226 and 239 Assy	UO_2-PuO_2 pellets, Zr-clad	12 pins	NA	NA			0.324	
IE (Irradiation Effects)	UO_2 pellets, Zr-clad	Pins	27-17,600	7.833	0.867		0.012	

Table A.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at INEL (other than ICPP and NRF) (continued)								
LLR (LOFT Lead Rod)	UO_2 pellets, Zr-clad	7 pins	36-150	3.510	0.327			
LOC (Loss of Coolant)	UO_2 pellets, Zr-clad	60 pins	16-150	7.777	0.816		0.010	
LOFT (Loss of Fluid Test)	UO_2 pellets, Zr-clad	15+ assemblies	0-1,050	2,201.696	89.371		2.029	
MAPI (Mitsubishi Atomic Power Industries)	UO_2 pellets, Zr-clad	43 pins	2,990-8,770	22.499	1.267		0.032	
Miscellaneous fuel pins	UO_2 pellets, Zr-clad	Pins	Varies	173.354	1.758		2.626	
Miscellaneous rods and scrap	Scrap	Stored in 8 cans	Varies	13.553	1.197			
OPTRAN (Operational Transient)	UO_2 pellets, Zr-clad	Pins	0-15,000	19.669	0.472		0.087	
PBF (Power-Burst Facility)	UO_2-ZrO_2-CaO; Zr sleeves, SS-clad	108 pins	NA	725.690	132.890			
PCM (Power Coolant Mismatch)	UO_2 pellets, Zr-clad	30 pins	<70	18.828	6.557			
Peach Bottom	UO_2 pellets, Zr-clad, Zr-clad assy	1 assembly and pieces (depleted U)	NA	364.1	2.512		1.878	
RIA (Reactivity Initiated Accident)	UO_2 pellets, Zr-clad	23 pins	0-6,090	8.989	0.504		0.013	
H. B. Robinson	UO_2 pellets, Zr-clad	113 pins	28,000	263.916	1.890		2.153	
Saxton	UO_2 pellets, Zr-clad	21 pins	10,400-18,253	7.607	0.660		0.025	
SFD (Severe Fuel Damage)	UO_2 pellets, Zr-clad	143 pins	NA	50.867	2.711		0.150	

Table A.6 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at INEL (other than ICPP and NRF) (continued)								
TC (Thermocouple)	UO_2 pellets, Zr-clad	Pins	0-<20	6.186	0.683			
TMI-Unit 2	Rubble	360 cans	NA	(Quantities unknown until entire core received)				
VEPCO (Virginia Electric Power Company)		69 assemblies (depleted U)	NA	30,207.295	242.457		172.695	
Subtotal				42,514.582	552.419		252.205	
Total at INEL				81,334.463	1,958.588	962.465	273.748	67,103.6

[a]See refs. 10-11. Many of the fuels at INEL have lower uranium enrichment than is found in those fuels that are normally processed. These fuels could be reprocessed in a special campaign, if required.
[b]Zr-clad = Zircaloy-clad.
[c]Data expressed in percentage.
[d]Based on ref. 11.
[e]Turkey Point Fuel.
NA = not available.

Table A.7. Miscellaneous radioactive materials stored at the Los Alamos National Laboratory, as of December 31, 1991[a]

Source of material	Composition	Description	U content, kg			Total Pu content (kg)
			Total	^{235}U	^{233}U	
EBR-2[b]	U-Pu oxide, carbide, or nitride SS-clad fuel rod segments	0.3-in. diam x 13.5 in.	3.09	1.84	0.058	1.31
Total			3.09	1.84	0.058	1.31

[a]See ref. 12.
[b]Information regarding the burnup of this fuel is not available.

Table A.8. Miscellaneous radioactive materials stored at the Oak Ridge National Laboratory, as of December 31, 1991[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)
				Total	^{235}U	^{233}U	
CEU (Consolidated Edison Uranium)	U_3O_8-CdO solid cake	Stored in 401 3.5-in.-OD x 24-in. SS cans	c	1,044.38	797.70	101.32	
Dresden-1	UO_2, Zr-clad	Sheared fuel pins stored in two 1-qt paint cans	~24,000	5.00	0.024		0.020
		9/16-in.-diam x 8-in. fuel rod sections plus short lengths	20,000	0.930	0.005		0.006
GETR (General Electric Test Reactor)	UO_2, Zr-clad	9/16-in.-diam x 8-in. fuel test capsules	1,000-2,000	0.399	0.022		
Monticello	UO_2, Zr-clad	1/2-in.-diam x 6-in. fuel rod sections plus short lengths	40,000	1.00	0.004		0.008
MSRE[d] (Molten Salt Reactor Experiment)	LiF-BeF_2-ZrF_4-UF_4	See ref. 13	~5 x 10^4 Ci total (see ref. 13)	36.95	0.940	31.01	0.743
Oconee-1	UO_2, Zr-clad	1/2-in.-diam x 6-in. fuel rod sections plus short lengths	38,000	1.00	0.005		0.005
Peach Bottom-2	UO_2, Zr-clad	9/16-in.-diam x 8-in. fuel rod sections plus short lengths	10,000	0.324	0.001		0.001
Quad City-1	UO_2, Zr-clad	1/2-in.-diam x 6-in. fuel rod sections plus short lengths	40,000	1.00	0.004		0.008
H. B. Robinson	UO_2, Zr-clad	1/2-in.-diam x 12-in. fuel rod sections plus short lengths	30,000	1.00	0.005		0.004
BR-3 (Belgium)	UO_2, Zr-clad	3/8-in.-diam x 6-in. fuel rod lengths	42,000	0.837	0.020		0.006
ORNL Inventory Item Nos. AUA-67/AUA-70 from LANL	U metal chunks	Stored in two 3.75-in.-OD x 18-in. SS cans	c	6.02		5.89	
CZA-91 from ANL	UO_x powder	Stored in one 3.5-in.-OD x 13-in. SS can	c	0.881		0.856	

Table A.8 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)
				Total	^{235}U	^{233}U	
HUA-2A from HEDL	UO_x powder	Stored in five 3.75-in.-OD x 7-in. SS cans	c	0.317		0.307	
LAE-03 from Atomics International (AI)	Metal	Stored in one 3-in.-OD x 10-in. SS can	c	0.01		0.01	
RCP-02 from SRO	UO_2 powder	Stored in thirty-two 3.5-in.-OD x 24-in. SS cans	c	11.14		10.72	
RCP-03 from SRO	UO_2 powder	Stored in 140 3.88-in.-OD x 10-in. SS cans	c	67.41		61.61	
RCP-04 from SRO	UF_4-LiF powder converted from UO_2	Stored in four 3.5-in.-OD x 24-in. SS cans	c	3.19		2.92	
RCP-06	U_3O_8-CdO solid cake	Stored in twenty-seven 3.5-in.-OD x 24-in. SS cans	c	65.55		60.60	
RCP-20/JZBL from LANL	U metal chunks	Stored in six 3.5-in.-OD x 24-in. SS cans	c	5.15		5.05	
Total				1,252.488	798.7	280.29	0.801

[a]See ref. 13.
[b]Zr-clad = Zircaloy-clad.
[c]No information regarding the burnup of this fuel is available.
[d]The Molten Salt Reactor Experiment was concluded in 1969, and the fuel has never been removed from the facility. A surveillance and monitoring program has been in force since shutdown. See ref. 14. Decommissioning of the MSRE facility is an environmental restoration activity discussed earlier in Chapter 6.

Table A.9. Miscellaneous radioactive materials stored at the Savannah River Site, as of December 31, 1991[a]

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at SRS								
CANDU (Canadian Deuterium Reactor)	UO_2, Zr-clad	Rods stored in three 5.0-in.-diam x 14-ft cans; pieces stored in three 3.5-in.-diam x 1-ft cans	6,500	50.07	0.231			
Carolinas-Virginia Tube Reactor	UO_2-Zr or SS-clad	One bundle of 34 rods in a 5.0-in.-diam x 14-ft can	Unknown	67.27	0.640		0.200	
Dresden	UO_2-ThO_2, SS-clad	Intact assemblies stored in 4.4-in. x 4.4-in. x 135-in. cans	4,000-10,000	684.00	37.545	15.391	1.879	1,857.0
ERR (Elk River Reactor)	UO_2-ThO_2, SS-clad	Assemblies 3.5 in. x 3.5 in. x 81.62 in.	Max. 50,000	224.29	186.159	14.722		4,818.6
LWR samples (Light-Water Reactors)	UO_2-PuO_2, SS- and Zr-clad	Fuel rod pieces stored in five 3.75-in.-diam x 32.5-in.-long cans	Unknown	12.631	0.192		0.109	
Nereide (a French Experiment using DOE fuel)	UAl-Si_x, Al-clad	Materials Test Reactor plate-type fuel assembly 34.37 in. x 2.98 in. x 3.14 in.	600	35.42	7.015			
H. B. Robinson	UO_2-PuO_2, Zr-clad, SS casing	Four 6- to 8-in.-long fragments in 4.5-in.-diam x 32-in.-long can	6,800-30,000	0.51	0.004		0.003	
Saxton	UO_2-PuO_2, Zr- or SS-clad	567 rods stored in eight 5.0-in.-diam x 14-ft cans and 64 rods stored in one 3.75-in.-diam x 50-in. can	1,000	280.21	1.411		15.408	
	UO_2, Zr-clad	Multiple pins stored in four 5.0-in.-diam x 14-ft cans and one bundle stored in one 12-in.-diam x 14-ft can	1,600	89.19	6.866		0.233	

Table A.9 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE/Civilian Development Programs material stored at SRS (continued)								
VBWR (Vallecitos Boiling-Water Reactor)	UO_2, Zr-clad	Stored in four 3.5-in.-diam x 12-in. cans	1,500	11.93	1.243		0.003	
Subtotal				1,455.521	241.306	30.113	17.835	6,675.6
DOE plus other government agencies material stored at SRS								
B&W scrap	UO_2-PuO_2, SS-clad	Stored in 3.5-in.-diam x 32-in. cans	6-54	0.025	0.013		0.048	
EBR-2 (Experimental Breeder Reactor)	UO_2-PuO_2, SS-clad (from ANL)	Eight rods stored in a 3.5-in.-diam x 30-in. can	120 kW total in 1975	0.44	0.376		0.114	
	UO_2-PuO_2, SS-clad (from HEDL)	Rod segments stored in 0.5-in.-diam x 42-in. cans	10,000-34,000	2.04	1.624		0.680	
EBWR (Experimental Boiling-Water Reactor)	UO_2, SS-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	1.73	1.612			
	UO_2, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	1,600.32	95.456			
	UO_2-Zr, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	7,482.73	73.967		9.092	
	UO_2-ZrO_2-CaO, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	28.93	26.651			
	UO_2-PuO_2, Zr-clad	Assemblies 3.75 in. x 3.75 in. x 62.5 in.	1,600	917.72	2.087		13.940	
EPR-1	PuO_2, SS-clad	Pieces stored in 4.5-in.-diam x 32-in. cans	Unknown				0.022	

Table A.9 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE plus other government agencies material stored at SRS (continued)								
GCRE (Gas-Cooled Reactor Experiment)	UO_2 or UO_2-BeO, Hastelloy-clad	Four 2-in.-diam x 32-in. Al cans of scrap pieces; two 1.5-in.-diam Al cans of plates; 66 pin-type assemblies		61.290	56.559			
HWCTR (Heavy-Water Components Test Reactor)	U and UO_2, Zr-clad	Intact assemblies 3 in. diam x 132 in. Pieces of assemblies stored in 3.5-in.-diam x 12-in. cans	6,200	1,051.376	9.470		0.565	
	U-Zr, Zr-clad			37.165	31.590			
HTRE (High-Temperature Reactor Experiment)	UO_2-BeO, Nichrome-clad	Segments and pieces of fuel assemblies and test pieces in thirteen 4-in.-diam x 36-in. Al cans		4.039	3.423			
ML-1 (Mobile Low Power Plant No. 1)	UO_2 and PuO_2-BeO, SS-clad	Sixty-eight 19-pin assemblies		58.575	54.478			
ORNL (Oak Ridge National Laboratory) SIW-1 rods	U, Zr-clad	Rods stored in three 4.5-in.-diam x 9.25-in. Al cans	Unknown but low	0.184	0.171			
ORNL mixed oxide	UO_2-PuO_2, Zr- or SS-clad	Stored in one 3.5-in.-diam x 15.12-in. can	Unknown but low	0.376	0.030		0.094	
Shippingport	UO_2, Zr-clad	Stored in a 10.5-in.-diam x 15-in. container	18,000	16.000	0.023		0.108	
SPERT-3 (Special Power Excursion Reactor Test)	UO_2, Zr-clad	Stored in three 4.0-in.-diam x 12-ft cans	Unknown	9.739	0.603			
SRE (Sodium Reactor Experiment)	U, Th rods, SS-clad	Stored in 3.5-in.-diam x 110.25-in. cans	10,000	154.934	143.410	1.045		1,972.6
	UC, SS-clad			44.324	4.344		0.016	

Table A.9 (continued)

Source of material	Composition[b]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)	Total Th content (kg)
				Total	^{235}U	^{233}U		
DOE plus other government agencies material stored at SRS (continued)								
SRS (Savannah River Site)	UO_2-PuO_2, Zr-clad	Stored in a 12.0-in.-diam x 14-ft can	Unknown	69.87	0.304		0.161	
ORR-LEU (Oak Ridge Reactor Low Enriched Uranium)	U_3Si_2, Al-clad	Stored in fourteen 3.5-in. x 3.5-in. x 168-in. Al cans	15,600	95.006	14.960	-	0.537	-
Subtotal				11,636.813	521.151	1.045	25.377	1,972.6
Total				13,092.334	762.457	31.158	43.212	8,648.2

[a]See refs. 14 and 15. The spent fuels listed in this table are not reprocessible in existing facilities.
[b]Zr-clad = Zircaloy-clad.

Table A.10. Volume and activity summary of commercial GTCC LLW[a,b]

Category	Volume (m^3)	Activity (Ci)
Nuclear utility wastes		
• Operations	1,330	23,300,000
• Decommissioning	523	41,700,000
Subtotal	1,853	65,000,000
Sealed sources	6	302,890
DOE-held potential GTCC waste	1,076	538,275
Other generator waste	307	2,924
Total	3,242	65,844,089

[a]Based on the EG&G Idaho, Inc., study of ref. 16. Data reported represent packaged base case scenario inventories and projections of wastes generated during the period 1985-2035.

[b]These wastes are discussed in Chapter 4; see Table 4.19.

Table A.11. Mass summary of DOE spent fuel no longer scheduled for reprocessing[a]

Site/source	Spent fuel mass
Hanford	
• N Reactor[b]	2,100 MTIHM
• Shippingport PWR[b]	16 MTIHM
• Fast Flux Test Facility[c]	12 MTIHM
Subtotal	2,128 MTIHM
Idaho National Engineering Laboratory[d]	874 t
West Valley[e]	27 MTIHM
Savannah River[f]	0 MTIHM

[a]Compiled from refs. 17-21.

[b]Based on ref. 18.

[c]Based on ref. 19 and includes contributions from fresh fuel (1.9 MTIHM), partially used fuel (5.2 MTIHM), and spent fuel (4.9 MTIHM).

[d]Based on ref. 20. Mass reported is an estimate of total spent fuel mass after burnup. This estimate includes contributions from graphite fuels (including Fort St. Vrain reactor fuel), special fuels (including TMI-Unit 2 fuel), and naval reactor fuels.

[e]Based on ref. 17.

[f]Based on ref. 21. Savannah River currently plans to reprocess all production reactor fuel that has been irradiated.

APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES

APPENDIX B. CHARACTERISTICS OF IMPORTANT RADIONUCLIDES

B.1 DISCUSSION

The following Table B.1 lists radionuclides whose characteristics are most often referenced in the variety of studies and evaluations discussed in Chapters 1–7. It includes isotopes for HLW, TRU waste, LLW, and uranium mill tailings as defined by EPA,[1] NRC,[2,3] and DOE.[4,5] The data in Table B.1 were obtained from refs. 6–8.

B.2 REFERENCES

1. U.S. Environmental Protection Agency, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Code of Federal Regulations, 40 CFR Part 191 (1985).

2. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste," Code of Federal Regulations, 10 CFR Part 61 (1982).

3. U.S. Nuclear Regulatory Commission, "Biomedical Waste Disposal," Fed. Regist. 46(47), 16230-16234 (Mar. 11, 1981).

4. U.S. Department of Energy, DOE Order 5820.2A, Radioactive Waste Management, Sept. 26, 1988.

5. U.S. Department of Energy, Energy Information Administration, Domestic Uranium Mining and Milling Industry 1990 – Viability Assessment, DOE/EIA-0477(90), Washington, D.C. (December 1991).

6. D. C. Kocher, Radioactive Decay Data Tables, DOE/TIC-11026, Washington, D.C. (1981).

7. D. C. Kocher, A Radionuclide Decay Data Base – Index and Summary Table, NUREG/CR-1413, ORNL/NUREG-70, Oak Ridge National Laboratory, Oak Ridge, Tennessee (May 1980).

8. E. Browne and R. B. Firestone, V. S. Shirley, ed., Table of Radioactive Isotopes, John Wiley and Sons, Inc., New York (1986).

Table B.1. Characteristics of important radionuclides[a]

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{3}H	1	1.233E+01 y	β		0.00568		5.68E-03	3.37E-05	9.650E+03	^{3}He
^{14}C	6	5.730E+03 y	β		0.0495		4.95E-02	2.93E-04	4.457	^{14}N
^{32}P	15	14.282 d	β		0.6947		6.95E-01	4.12E-03	2.853E+05	^{32}S
^{35}S	16	87.51 d	β		0.0486		4.86E-02	2.88E-04	4.263E+04	^{35}Cl
^{36}Cl	17	3.01E+05 y	β (98.1%); EC (1.9%)		0.2460		2.460E-01	1.458E-03	3.299E-02	^{36}Ar; ^{36}S
^{45}Ca	20	163.8 d	β		0.0770		7.70E-02	4.56E-04	1.780E+04	^{45}Sc
^{46}Sc	21	83.83 d	β	0.1120	2.0095		2.122E+00	1.257E-02	3.381E+04	^{46}Ti
^{51}Cr	24	27.704 d	EC		0.0031	0.0325	3.56E-02	2.11E-04	9.240E+04	^{51}V
^{54}Mn	25	312.20 d	EC		0.0034	0.8360	8.394E-01	4.975E-03	7.738E+03	^{54}Cr
^{55}Fe	26	2.73 y	EC		0.0038	0.0016	5.4E-03	3.2E-05	2.500E+03	^{55}Mn
^{59}Fe	26	44.496 d	β		0.1174	1.1882	1.3056	7.741E-03	4.918E+04	^{59}Co
^{57}Co	27	271.77 d	EC		0.0176	0.1252	1.428E-01	8.464E-01	8.456E+03	^{57}Fe
^{58}Co	27	70.92 d	EC		0.0336	0.9758	1.0094	5.99E-03	3.181E+04	^{58}Fe
^{60}Co	27	5.271 y	β		0.0958	2.5058	2.6016	1.541E-02	1.131E+03	^{60}Ni
^{60m}Co	27	10.47 min	IT (99.75%); β (0.25%)		0.0536	0.0066	6.02E-02	3.57E-04	2.993E+08	^{60}Co; ^{60}Ni
^{59}Ni	28	7.5E+04 y	EC		0.0043	0.0024	6.72E-03	3.98E-05	7.574E+04	^{59}Co
^{63}Ni	28	1.001E+02 y	β		0.0171		1.71E-02	1.01E-04	6.168E+01	^{63}Cu
^{65}Zn	30	244.1 d	EC		0.0066	0.5838	5.90E-01	3.51E-03	8.237E+03	^{65}Cu
^{67}Ga	31	3.261 d	EC		0.0333	0.1549	1.882E-01	1.115E-03	5.975E+05	^{67}Zn
^{75}Se	34	119.77 d	EC		0.0134	0.3924	4.06E-01	2.41E-03	1.453E+04	^{75}As
^{79}Se	34	<6.5E+04 y			0.0529		5.29E-02	3.13E-04	6.966E-02	^{79}Br
^{85}Kr	36	1.072E+01 y	β		0.2505	0.0022	2.53E-01	1.50E-03	3.923E+02	^{85}Rb
^{86}Rb	37	18.66 d	β		0.6670	0.0945	7.62E-01	4.52E-03	8.138E+04	^{86}Sr
^{89}Sr	38	50.55 d	β		0.5829	0.0001	5.83E-01	3.46E-03	2.905E+04	^{89}Y
^{90}Sr	38	2.85E+01 y	β		0.1958		1.96E-01	1.16E-03	1.364E+02	^{90}Y

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{90}Y	39	2.671 d	β		0.9332		9.33E-01	5.54E-03	5.441E+05	^{90}Zr
^{91}Y	39	58.51 d	β		0.6039	0.0036	6.07E-01	3.60E-03	2.452E+04	^{91}Zr
^{93}Zr	40	1.53E+06 y	β		0.0471	0.0018	4.89E-02	2.90E-04	2.513E-03	^{93}Nb
^{95}Zr	40	64.02 d	β		0.1200	0.7337	8.54E-01	5.06E-03	2.148E+04	^{95}Nb
^{93m}Nb	41	1.36E+01 y	IT		0.0281	0.0018	2.99E-02	1.77E-04	2.826E+02	^{93}Nb
^{94}Nb	41	2.03E+04 y	β		0.1454	1.5715	1.7169	1.018E-02	1.873E-01	^{94}Mo
^{95}Nb	41	34.97 d	β		0.0435	0.7643	8.078E-01	4.788E-03	3.910E+04	^{95}Mo
^{99}Mo	42	2.748 d	β		0.4076	0.2723	6.799E-01	4.028E-03	4.796E+05	^{99}Tc
^{99}Tc	43	2.13E+05 y	β		0.0846		8.46E-02	5.01E-04	1.695E-02	^{99}Ru
^{99m}Tc	43	6.006 h	IT		0.0142	0.1240	1.382E-01	8.186E-04	5.271E+06	^{99}Tc
^{103}Ru	44	39.254 d	β		0.1105	0.4851	5.96E-01	3.53E-03	3.227E+04	^{103}Rh
^{106}Ru	44	1.020 y	β		0.1004		1.004E-01	5.951E-04	3.346E+03	^{106}Rh
^{103m}Rh	45	56.12 min	IT		0.0375	0.0017	3.92E-02	2.32E-04	3.253E+07	^{103}Rh
^{106}Rh	45	2.17 h	β		0.3144	2.8826	3.197	1.894E-02	3.560E+09	^{106}Pd
^{107}Pd	46	6.5E+06 y	β			0.0093	9.3E-03	5.5E-05	5.143E-04	^{107}Ag
^{110}Ag	47	24.6 s	β (99.70%); EC (0.30%)		1.1842	0.0316	1.216	7.208E-03	4.169E+09	^{110}Cd; ^{110}Pd
^{110m}Ag	47	249.76 d	β (98.64%); IT (1.36%)		0.0755	2.7392	2.815	1.669E-02	4.750E+03	^{110}Cd; ^{110}Ag
^{113m}Cd	48	1.37E+01 y	β (99.9%); IT (0.1%)			0.1834	1.83E-01	1.08E-03	2.168E+02	^{113}In; ^{113}Cd
^{115m}Cd	48	44.6 d	β		0.6029	0.0329	6.36E-01	3.76E-03	2.546E+04	^{115}In
^{111}In	49	2.807 d	EC		0.0340	0.4053	4.393E-01	2.604E-03	4.157E+05	^{111}Cd
^{113m}In	49	1.658 h	IT		0.1340	0.2555	3.89E-01	2.31E-03	1.673E+07	^{113}In
^{114m}In	49	49.51 d	IT (95.7%); EC (4.3%)		0.1431	0.0943	2.37E-01	1.40E-03	2.313E+04	^{114}In; ^{114}Cd
^{113}Sn	50	115.09 d	EC		0.1394	0.2808	4.20E-01	2.48E-03	1.004E+04	^{113}In
^{117m}Sn	50	13.61 d	IT		0.1613	0.1580	3.19E-01	1.89E-03	7.969E+04	^{117}Sn
^{119m}Sn	50	293.0 d	IT		0.0783	0.0114	8.97E-02	5.32E-04	4.478E+03	^{119}Sn
^{121m}Sn	50	5.5E+01 y	IT (77.6%); β (22.4%)		0.0352	0.0050	4.02E-02	2.43E-04	5.912E+01	^{121}Sn; ^{121}Sb
^{123}Sn	50	129.2 d	β		0.5222	0.0069	5.29E-01	3.14E-03	8.219E+03	^{123}Sb
^{125}Sn	50	9.64 d	β		0.8110	0.3124	1.123	6.656E-03	1.084E+05	^{125}Sb
^{126}Sn	50	~1E+05 y	β		0.1249	0.0573	1.82E-01	1.08E-03	2.837E-02	^{126}Sb

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{124}Sb	51	60.20 d	β		0.3897	1.8523	2.242	1.329E-02	1.749E+04	^{124}Te
^{125}Sb	51	2.73 y	β		0.1257	0.4434	5.69E-01	3.37E-03	1.032E+03	^{125}Te
^{126}Sb	51	12.4 d	β		0.3527	2.7496	3.102	1.839E-02	8.360E+04	^{126}Te
^{126m}Sb	51	19.0 min	β (86%); IT (14%)		0.6323	1.5484	2.181	1.292E-02	7.854E+07	^{126}Te; ^{126}Sb
^{123m}Te	52	119.7 d	IT		0.1020	0.1482	2.502E-01	1.482E-03	8.870E+03	^{123}Te
^{125m}Te	52	58 d	IT		0.1106	0.0361	1.467E-01	8.690E-04	1.801E+04	^{125}Te
^{127}Te	52	9.35 h	β		0.2248	0.0048	2.30E-01	1.36E-03	2.639E+06	^{127}I
^{127m}Te	52	109 d	IT (97.6%); β (2.4%)		0.0821	0.0111	9.32E-02	5.52E-04	9.432E+03	^{127}Te; ^{127}I
^{129}Te	52	1.160 h	β		0.5422	0.0624	6.05E-01	3.58E-03	2.094E+07	^{129}I
^{129m}Te	52	33.6 d	IT (64%); β (36%)		0.2663	0.0370	3.03E-01	1.80E-03	3.013E+04	^{129}Te; ^{129}I
^{123}I	53	13.2 h	EC		0.0276	0.1729	2.005E-01	1.188E-03	1.940E+06	^{123}Te
^{125}I	53	60.14 d	EC		0.0179	0.0423	6.02E-02	3.57E-04	1.737E+04	^{125}Te
^{129}I	53	1.57E+07 y	β		0.0556	0.0248	8.04E-02	4.77E-04	1.765E-04	^{129}Xe
^{131}I	53	8.040 d	β		0.1913	0.3826	5.74E-01	3.40E-03	1.240E+05	^{130}Xe
^{133}Xe	54	5.245 d	β		0.1363	0.0459	1.82E-01	1.08E-03	1.872E+05	^{133}Cs
^{134}Cs	55	2.062 y	β		0.1639	1.5555	1.719	1.019E-02	1.294E+03	^{134}Ba
^{135}Cs	55	3.0E+06 y	β		0.0563		5.63E-02	3.32E-04	1.151E-03	^{135}Ba
^{137}Cs	55	3.017E+01 y	β (94.6%); β (5.4%)			0.1708	1.71E-01	1.01E-03	8.698E+01	^{137m}Ba; ^{137}Ba
^{133}Ba	56	1.054E+01 y	EC		0.0547	0.4045	4.592E-01	2.722E-03	2.500E+02	^{133}Cs
^{137m}Ba	56	2.552 min	IT		0.0652	0.5991	6.64E-02	3.94E-03	5.379E+08	^{137}Ba
^{141}Ce	58	32.50 d	β		0.1707	0.0770	2.48E-01	1.47E-03	2.848E+04	^{141}Pr
^{144}Ce	58	284.9 d	β		0.0918	0.0192	1.11E-01	6.58E-04	3.190E+03	^{144}Pr
^{143}Pr	59	13.58 d	β		0.3156		3.16E-01	1.87E-03	6.731E+04	^{143}Nd
^{144}Pr	59	17.28 min	β		1.2091	0.0289	1.238	7.338E-03	7.555E+07	^{144}Nd
^{144m}Pr	59	7.2 min	IT (99.96%); β (0.04%)		0.0464	0.0121	5.85E-02	3.43E-04	1.814E+08	^{144}Pr; ^{144}Nd
^{146}Pm	61	5.53 y	EC (66.1%); β (33.9%)		0.0928	0.7542	8.47E-01	5.02E-03	4.428E+02	^{146}Nd; ^{146}Sm
^{147}Pm	61	2.6234 y	β		0.6196		6.20E-02	3.67E-04	9.270E+02	^{147}Sm
^{148}Pm	61	5.370 d	β		0.7235	0.5747	1.298	7.691E-03	1.643E+05	^{148}Sm
^{148m}Pm	61	41.29 d	β (95.4%); IT (4.6%)		0.1695	1.9861	2.156	1.278E-02	2.136E+04	^{148}Sm; ^{148}Pm

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)		
^{151}Sm	62	9.0E+01 y	β		0.1251		1.25E-01	7.41E-04	2.631E+01	^{151}Eu
^{152}Eu	63	1.333E+01 y	EC (72.08%); β (27.92%)		0.1275	1.1628	1.290	7.646E-03	1.729E+02	^{152}Sm; ^{152}Gd
^{154}Eu	63	8.8 y	β		0.2794	1.2531	1.532	9.081E-03	2.699E+02	^{154}Gd
^{155}Eu	63	4.96 y	β		0.0650	0.0633	1.28E-01	7.59E-04	4.651E+02	^{155}Gd
^{153}Gd	64	241.6 d	EC		0.0399	0.1015	1.414E-01	8.381E-04	3.526E+03	^{153}Eu
^{160}Tb	65	72.3 d	β		0.2535	1.1271	1.381	8.186E-03	1.129E+04	^{160}Dy
^{169}Yb	70	32.02 d	EC		0.1117	0.3121	4.238E-01	2.512E-03	2.414E+04	^{169}Tm
^{175}Hf	72	70.0 d	EC		0.0439	0.3646	4.085E-01	2.422E-03	1.066E+04	^{175}Lu
^{182}Ta	73	115.0 d	β		0.2073	1.3011	1.508	8.940E-03	6.253E+03	^{182}W
^{192}Ir	77	73.831 d	β (95.4%); EC (4.6%)		0.2162	0.8137	1.030	6.105E-03	9.211E+03	^{192}Pt; ^{192}Os
^{201}Tl	81	3.046 d	EC		0.0481	0.0924	1.40E-01	8.30E-04	2.132E+05	^{201}Hg
^{207}Tl	81	4.77 min	β		0.4931	0.0022	4.95E-01	2.93E-03	1.904E+08	^{207}Pb
^{208}Tl	81	3.053 min	β		0.5979	3.3742	3.972	2.354E-02	2.945E+08	^{208}Pb
^{209}Pb	82	3.253 h	β		0.1980		1.98E-01	1.17E-03	4.544E+06	^{209}Bi
^{211}Pb	82	36.1 min	β		0.4523	0.0678	5.20E-01	3.083E-03	2.468E+07	^{211}Bi
^{212}Pb	82	10.64 h	β		0.1752	0.1453	3.20E-01	1.90E-03	1.389E+06	^{212}Bi
^{211}Bi	83	2.14 min	α (99.727%); β (0.273%)	6.5505	0.0099	0.0467	6.607	3.916E-02	4.184E+08	^{207}Tl; ^{211}Po
^{212}Bi	83	1.0092 h	α (35.94%); β (64.06%)	2.1740	0.5025	0.1061	2.783	1.649E-02	1.465E+07	^{208}Tl; ^{212}Po
^{213}Bi	83	45.59 min	α (2.16%); β (97.84%)	0.1268	0.4563	0.0825	6.66E-01	3.95E-03	1.934E+07	^{209}Tl; ^{213}Po
^{212}Po	84	2.98E-07 s	α	8.7844			8.784	5.207E-02	1.774E+17	^{208}Pb
^{213}Po	84	4.2E-06 s	α	8.3757			8.375	4.964E-02	1.261E+16	^{209}Pb
^{215}Po	84	1.780E-03 s	α	7.3864			7.386	4.378E-02	2.948E+13	^{211}Pb
^{216}Po	84	1.50E-02 s	α	6.7785			6.779	4.018E-02	3.482E+11	^{212}Pb
^{217}At	85	3.23E-02 s	α	7.0657		0.0002	7.066	4.189E-02	1.610E+12	^{213}Bi
^{219}Rn	86	3.96 s	α	6.8122	0.0064	0.0560	6.875	4.076E-02	1.301E+10	^{215}Po
^{220}Rn	86	55.6 s	α	6.2878		0.0005	6.288	3.727E-02	9.223E+08	^{216}Po
^{222}Rn	86	3.825 d	α	5.4892		0.0004	5.490	3.255E-02	1.538E+05	^{218}Po

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity (Ci/g)	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)		
^{221}Fr	87	4.9 min	α	6.3571	0.0084	0.0277	6.393	3.789E-02	1.772E+08	^{217}At
^{223}Fr	87	21.8 min	β		0.3805	0.0542	4.35E-01	2.85E-03	3.868E+07	^{223}Ra
^{223}Ra	88	11.43 d	α	5.6972	0.0731	0.1348	5.905	3.500E-02	5.121E+04	^{219}Rn
^{224}Ra	88	3.66 d	α	5.6751	0.0022	0.0103	5.688	3.372E-02	1.593E+05	^{220}Rn
^{225}Ra	88	14.2 d	β		0.1057	0.0137	1.19E-01	7.08E-04	3.920E+04	^{225}Ac
^{226}Ra	88	1.600E+03 y	α	4.7741	0.0035	0.0067	4.784	2.836E-02	9.887E-01	^{222}Rn
^{228}Ra	88	5.75 y	β		0.0116		1.16E-02	6.88E-05	2.340E+02	^{228}Ac
^{225}Ac	89	10.0 d	α	5.7501	0.0257	0.0176	5.793	3.434E-02	5.803E+04	^{221}Fr
^{227}Ac	89	2.177E+01 y	β (98.62%); α (1.38%)	0.0673	0.0125	0.0002	8.00E-02	4.74E-04	7.233E+01	^{227}Th; ^{223}Fr
^{228}Ac	89	6.13 h	β		0.4292	0.9269	1.356	8.038E-03	2.242E+06	^{228}Th
^{227}Th	90	18.718 d	α	5.9022	0.0543	0.1113	6.068	3.597E-02	3.073E+04	^{223}Ra
^{228}Th	90	1.913 y	α	5.3992	0.0201	0.0034	5.423	3.214E-02	8.196E+02	^{224}Ra
^{229}Th	90	7.340E+03 y	α	4.8620		0.0343	4.896	2.902E-02	2.127E-01	^{225}Ra
^{230}Th	90	7.54E+04 y	α	4.6651		0.0004	4.665	2.765E-02	2.109E-02	^{226}Ra
^{231}Th	90	1.0633 d	β	0.1732		0.0295	2.03E-01	1.21E-03	5.316E+05	^{231}Pa
^{232}Th	90	1.405E+10 y	α	4.0056		0.0002	4.006	2.375E-02	1.097E-07	^{228}Ra
^{234}Th	90	24.10 d	β		0.0158	0.0094	2.52E-02	1.49E-04	2.316E+04	^{234}Pa
^{231}Pa	91	3.276E+04 y	α	4.9230	0.0483	0.0399	5.011	2.970E-02	4.723E-02	^{227}Ac
^{233}Pa	91	27.0 d	β		0.1941	0.2042	3.98E-01	2.36E-03	2.075E+04	^{233}U
^{234m}Pa	91	1.17 min	β (99.87%); IT (0.13%)		0.8227	0.0121	8.35E-01	4.95E-03	6.868E+08	^{234}U; ^{234}Pa
^{232}U	92	6.89E+01 y	α	5.3065		0.0002	5.307	3.146E-02	2.140E+01	^{228}Th
^{233}U	92	1.592E+05 y	α	4.8141	0.0055	0.0013	4.821	2.857E-02	9.680E-03	^{229}Th
^{234}U	92	2.454E+05 y	α	4.7732		0.0001	4.773	2.829E-02	6.248E-03	^{230}Th
^{235}U	92	7.037E+08 y	α	4.3785	0.0426	0.1561	4.577	2.713E-02	2.161E-06	^{231}Th
^{236}U	92	2.342E+07 y	α	4.4793	0.0108	0.0015	4.492	2.662E-02	6.469E-05	^{232}Th
^{238}U	92	4.468E+09 y	α	4.1945	0.0095	0.0013	4.205	2.492E-02	3.362E-07	^{234}Th
^{236}Np	93	1.550E+05 y	EC (91%); β (8.9%); α (0.20%)		0.1967	0.1411	3.38E-01	2.00E-03	1.317E-02	^{236}U; ^{236}Pu; ^{232}Pa
^{237}Np	93	2.140E+06 y	α	4.7604	0.0640	0.0327	4.857	2.879E-02	7.049E-04	^{233}Pa
^{239}Np	93	2.355 d	β		0.2521	0.1740	4.26E-01	2.53E-03	2.320E+05	^{239}Pu
^{236}Pu	94	2.851 y	α	5.7521	0.0126	0.0020	5.767	3.418E-02	5.313E+02	^{232}U
^{238}Pu	94	8.774E+01 y	α	5.4871	0.0099	0.0018	5.499	3.2593E-02	1.712E+01	^{234}U
^{239}Pu	94	2.411E+04 y	α	5.1011		0.0001	5.101	3.024E-02	6.216E-02	^{235}U
^{240}Pu	94	6.563E+03 y	α	5.1549			5.155	3.056E-02	2.279E-01	^{236}U
^{241}Pu	94	1.44E+01 y	β	0.0001		0.0052	5.3E-03	3.2E-05	1.030E+02	^{241}Am

Table B.1 (continued)

Nuclide	Atomic number	Half-life[b]	Principal mode(s) of decay[c]	Major radiation energies[d] (MeV/dis)			"Q" value[e]		Specific activity	Daughter(s)
				α	e	γ(X)	(MeV/dis)	(W/Ci)	(Ci/g)	
^{242}Pu	94	3.763E+05 y	α	4.8901	0.0081	0.0014	4.900	2.904E-02	3.818E-03	^{238}U
^{244}Pu	94	8.26E+07 y	α (99.875%); SPF (0.125%)	4.5751	0.0007	0.0001	4.576	2.712E-02	1.774E-05	^{240}U; (fission products)
^{241}Am	95	4.327E+02 y	α	5.4801	0.0304	0.0287	5.539	3.283E-02	3.432	^{237}Np
^{242}Am	95	16.01 h	β (82.7%); EC (17.3%)		0.1781	0.0180	1.96E-01	1.16E-03	8.084E+05	^{242}Cm; ^{242}Pu
^{242m}Am	95	1.41E+02 y	IT (99.55%); α (0.45%)	0.0232	0.0403	0.0049	6.84E-02	4.05E-04	9.718	^{242}Am; ^{238}Np
^{243}Am	95	7.380E+03 y	α	5.2656		0.0481	5.3137	3.1496E-02	1.993E-01	^{239}Np
^{242}Cm	96	162.94 d	α	6.0434	0.0090	0.0018	6.0542	3.5886E-02	3.306E+03	^{238}Pu
^{243}Cm	96	2.85E+01 y	α (99.76%); EC (0.24%)	5.8380	0.1129	0.1316	6.083	3.605E-02	5.162E+01	^{239}Pu; ^{243}Am
^{244}Cm	96	1.811E+01 y	α	5.7965		0.0016	5.798	3.437E-02	8.090E+01	^{240}Pu
^{245}Cm	96	8.5E+03 y	α	5.3631	0.1342	0.1178	5.615	3.329E-02	1.717E-01	^{241}Pu
^{246}Cm	96	4.73E+03 y	α	5.3764	0.0072	0.0014	5.385	3.192E-02	3.072E-01	^{242}Pu
^{247}Cm	96	1.56E+07 y	α	4.9475		0.3152	5.263	3.119E-02	9.278E-05	^{243}Pu
^{248}Cm	96	3.40E+05 y	α (91.74%); SPF (8.26%)	4.6524			4.6524	2.7577E-02	4.251E-03	^{244}Pu; (fission products)
^{252}Cf	98	2.645 y	α (96.908%); SPF (3.092%)	5.9308	0.0051	0.0011	5.9370	3.5191E-02	5.378E+02	^{248}Cm; (fission products)

[a]Based on refs. 6-8.

[b]y – years; d – days; h – hours; min – minutes; and s – seconds.

[c]α – alpha decay; β – negative beta decay; EC – electron capture; IT – isomeric transition (radioactive transition from one nuclear isomer to another of lower energy); and SPF – spontaneous fission.

[d]α – alpha decay; e – total electron emissions; and γ(X) – gamma and X-ray photons.

[e]The sum of the average energies per different radiation types in MeV/disintegration or W/Ci (includes alpha and beta particles, discrete electrons, and photons). The "Q" value indicates the amount of energy (heat) that could be deposited in a radioactive material from each decay event if none of the radiation escaped from the material.

APPENDIX C. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

APPENDIX C. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

C.1 DISCUSSION

In this report, a number of engineering estimates, assumptions, and ground rules are used to determine radioactive waste and spent fuel projections through the year 2030. Many of these involve parameters that characterize certain types of waste (e.g., see Table C.1). In other instances, estimates were made of the waste volume generated per unit of product throughput for each step in the fuel cycle. This appendix is a compilation of generic flowsheets and source terms used for making waste projections. Source terms are used to describe quantitative and qualitative characteristics of radioactive wastes. In general, the source term for a particular waste is comprised of two components unique to that waste: (1) the number of curies of radioactivity expressed either per unit of facility production or per unit of waste volume or mass and (2) a listing of the relative radioactivity contributions of component radioisotopes.

The source terms used in the analysis of this report are based on reported historical data, engineering estimates, calculations, and/or experimental data. Documentation of the source terms and key waste modeling parameters is provided in the following sets of figures and tables (based primarily on refs. 1 through 11). Detailed information on how these source terms and modeling parameters were derived is available, mainly in ref. 1 and its update (ref. 2). Figures C.1 through C.9 were taken from refs. 1 and 2. Figure C.10 was adapted from information presented in ref. 3. Table C.2 lists some basic factors used for estimating waste projections (including HLW estimates reported in ref. 4). Using these requirements, the source terms of Figs. C.1–C.9, and the spent fuel activity levels based on refs. 5 and 6, estimates were made of the spent fuel and waste generation by a 1-GW(e) reference BWR and a 1-GW(e) PWR for a 40-year operating life. The results are reported in Table C.3. The mass, radioactivity, and thermal power of the nuclides contained in all stored domestic commercial LWR spent fuel as of December 31, 1991, are listed in Table C.4.

Representative DOE LLW radionuclide compositions are described in Table C.5 (based on ref. 1). Average concentrations for representative radionuclides in LLW disposed of at commercial sites are given in Table C.6, which is based on data available in ref. 1. Table C.7, which gives the radionuclide composition of saltstone at SRS, summarizes information obtained from ref. 3. The data on LLW produced from commercial LWR operations are based on the annual LWR waste shipments to commercial disposal sites (refs. 7 and 8) and the energy generation values reported in Table C.8, which are based on refs. 7, 9, and 10. Table C.9 gives a summary of major sources and estimated characteristics of commercial greater-than-Class-C LLW (data from refs. 11 and 12). Information on the LLW to be incorporated in cement as a result of future operations by the West Valley Demonstration Project Radwaste Treatment System is presented in Table C.10, which is taken from ref. 13.

Compositions (adapted from ref. 2) of I/I wastes are given in Table C.11. These wastes are categorized according to I/I activities (bioresearch, medical, and nonbioresearch).

C.2 REFERENCES

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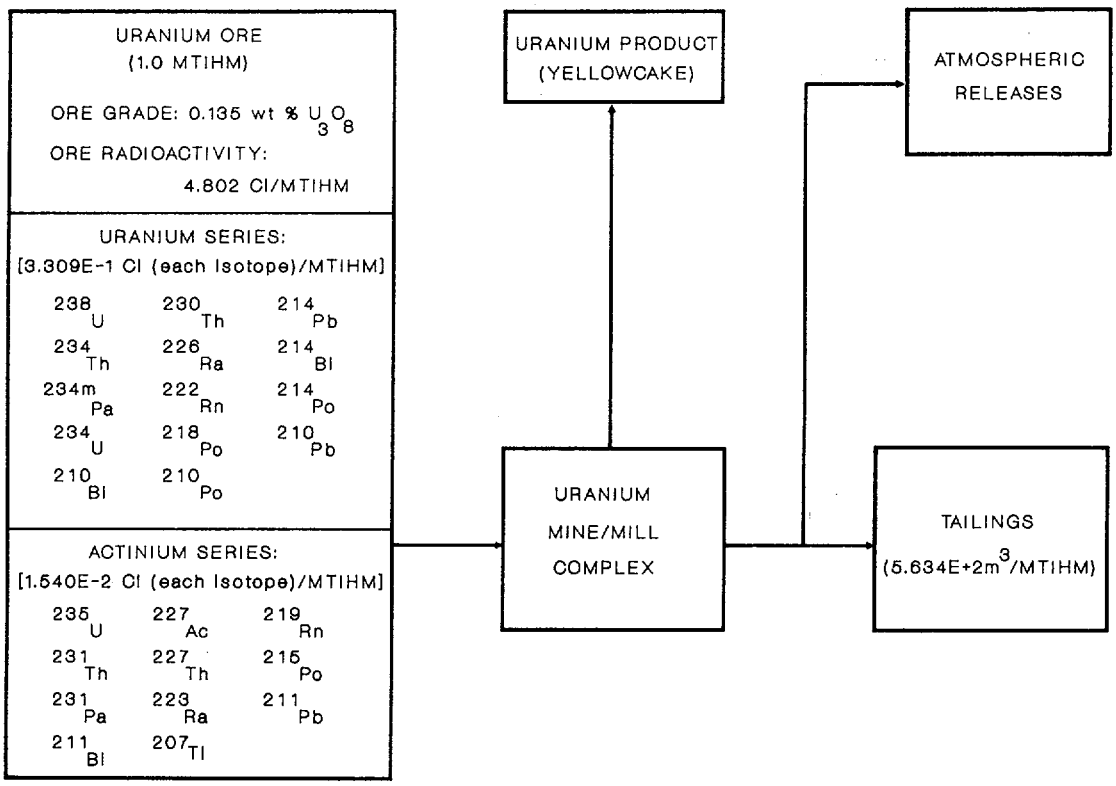
ORNL DWG 89-7803



Fractions of elements from uranium ore in waste and product streams from a uranium mine/mill complex

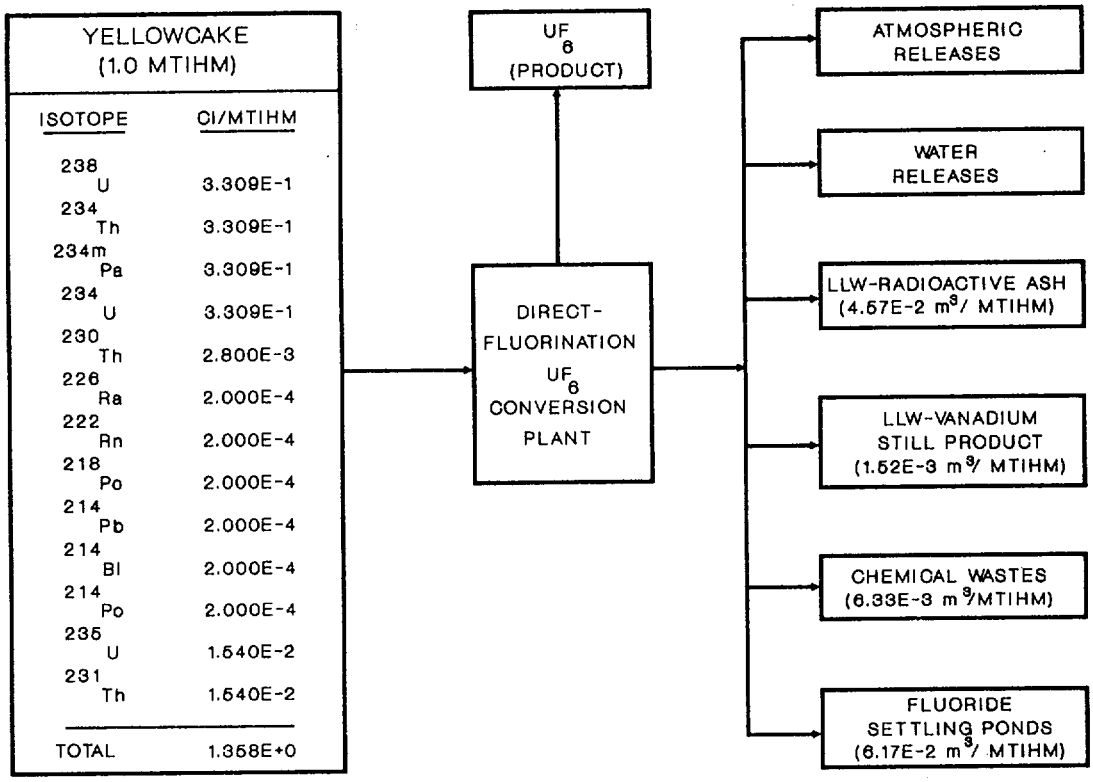
	Waste streams		Product stream[a]
Element	Atmospheric releases	Tailings[b]	Uranium (yellowcake)
Uranium	1.000E-3	6.800E-2	9.310E-1
Protactinium	0.000E+0	1.00OE+0	0.000E+0
Thorium	8.000E-6	9.923E-1	7.692E-3
Actinium	0.000E+0	1.000E+0	0.000E+0
Radon	1.000E-1	9.000E-1	0.000E+0
Other	6.000E-7	9.994E-1	5.994E-4

[a] Also includes yellowcake from both solution mining and by-product U_3O_8.

[b] Assumed density = 1.6 t/m^3.

Fig. C.1. Principal waste and product streams from a uranium mine/mill complex.

ORNL DWG 89-7804

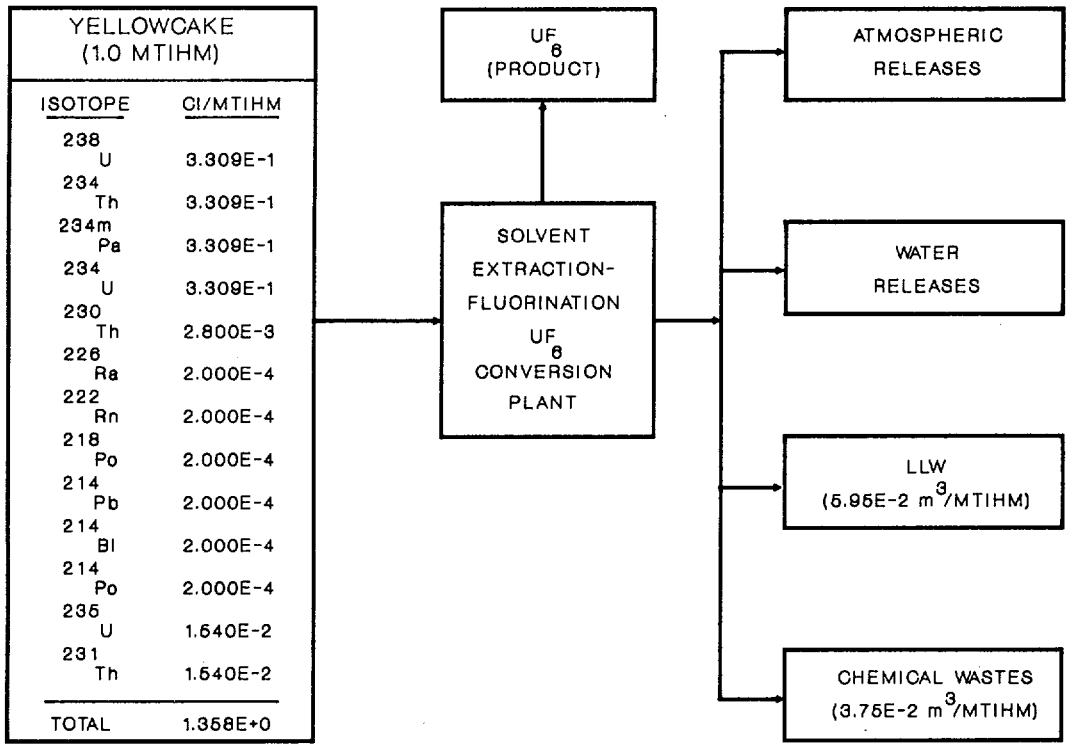


Fractions of elements from yellowcake in waste and product streams from a direct-fluorination UF_6 conversion plant

	Waste streams						
Element	Atmospheric releases	Water releases	Radioactive ash	Vanadium still product	Chemical wastes	Fluoride settling ponds	Product stream (UF_6)
Uranium	2.50E-5	7.65E-5	3.51E-5	5.01E-4	1.00E-6	3.63E-5	9.9932E-1
Thorium	3.22E-5	7.27E-6	1.00E+0	2.67E-5	1.00E-6	8.80E-7	0.00
Radium	3.36E-5	1.14E-3	9.99E-1	2.68E-5	1.00E-6	5.88E-6	0.00
Radon	8.21E-1	0.00	1.79E-1	4.84E-6	0.00	1.06E-6	0.00
Other	3.26E-5	7.25E-6	1.00E+0	2.67E-5	1.00E-6	3.80E-6	0.00

Fig. C.2. Principal waste and product streams from a direct-fluorination UF_6 conversion plant.

ORNL DWG 89-7805

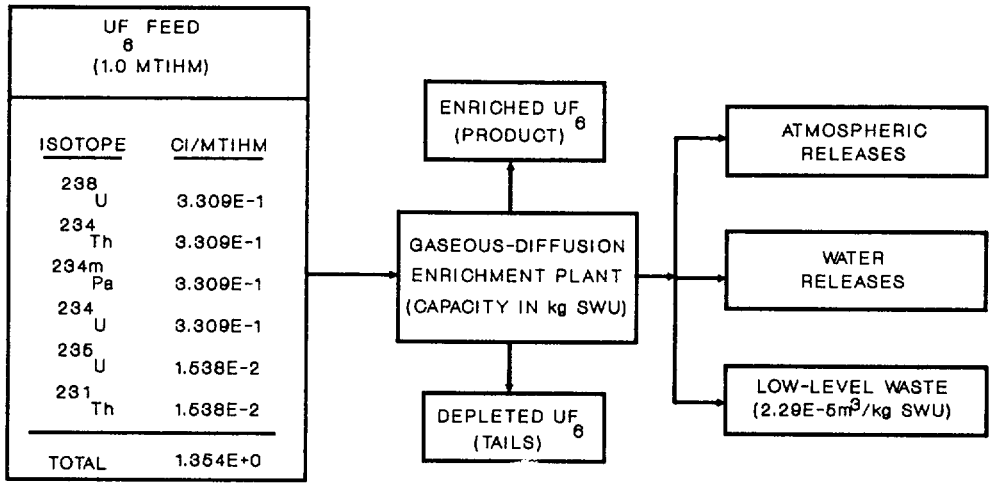


Fractions of elements from yellowcake in waste and product streams from a solvent extraction-fluorination UF_6 conversion plant

	Waste streams				
Element	Atmospheric releases	Water releases	Low-level wastes	Chemical wastes	Product stream (UF_6)
Uranium	1.35E-5	1.13E-9	2.54E-4	2.79E-5	9.997E-1
Protactinium	9.54E-6	6.54E-10	5.01E-1	2.79E-5	4.99E-1
Thorium	1.28E-5	1.15E-9	1.00E+0	2.50E-6	0.00
Other	5.35E-6	1.16E-11	1.00E+0	2.25E-6	0.00

Fig. C.3. Principal waste and product streams from a solvent extraction-fluorination UF_6 conversion plant.

ORNL DWG 92-6867



Separative work units required to produce 1.0 kg of enriched uranium from natural uranium by gaseous diffusion while generating tails containing 0.2 wt % ^{235}U

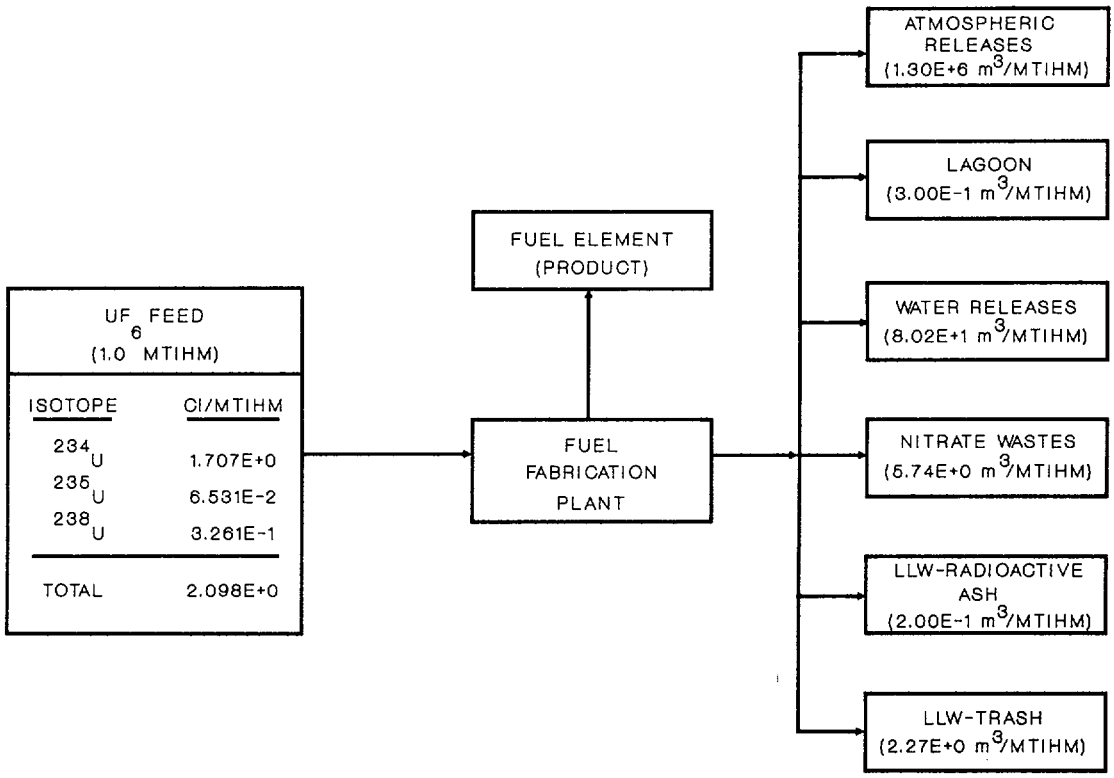
Product desired enrichment (wt % ^{235}U)	Feed natural (0.711 wt % ^{235}U) uranium (kg)	Separative work units (No. of kg SWU)
2	3.523	2.194
3	5.479	4.306
4	7.436	6.544

Fractions of elements from feed in waste and product streams from a gaseous-diffusion uranium enrichment plant

	Waste streams			
Element	Atmospheric releases	Water releases	LLW	Product and tails streams
Uranium	1.4E-6	6.1E-6	4.74E-5	9.9994E-1
Other	1.0E-3	2.0E-3	9.97E-1	0.0

Fig. C.4. Principal waste and product streams from a gaseous diffusion uranium enrichment plant.

ORNL DWG 89-7807

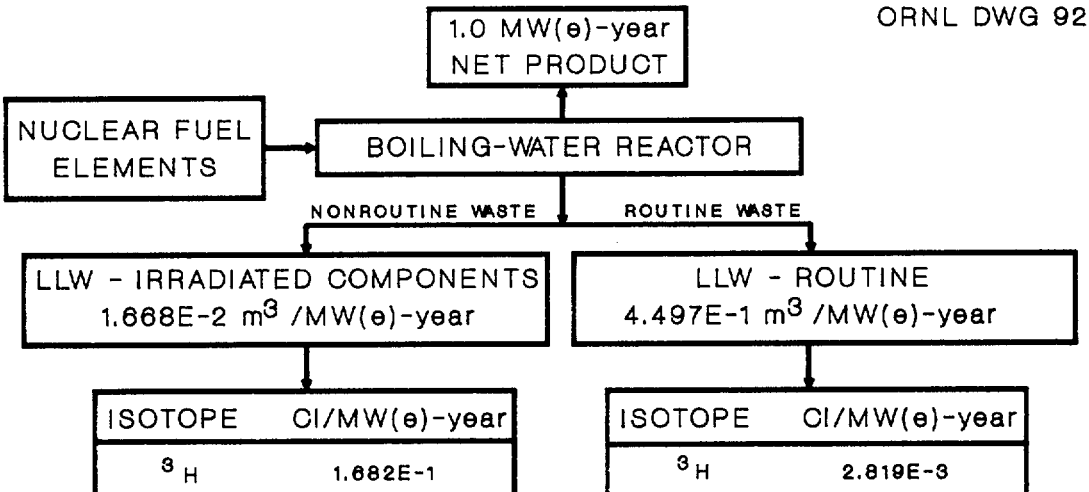


Fractions of uranium from feed in waste and product streams from a fuel fabrication plant

	Waste streams						
Element	Atmospheric releases	Lagoon	Water releases	Nitrate wastes	Radioactive ash	Trash	Product stream (fuel element)
Uranium	1.6E-6	9.6E-4	4.9E-4	1.1E-4	1.0E-6	2.8E-3	9.956E-1

Fig. C.5. Principal waste and product streams from a fuel fabrication plant.

ORNL DWG 92-6869



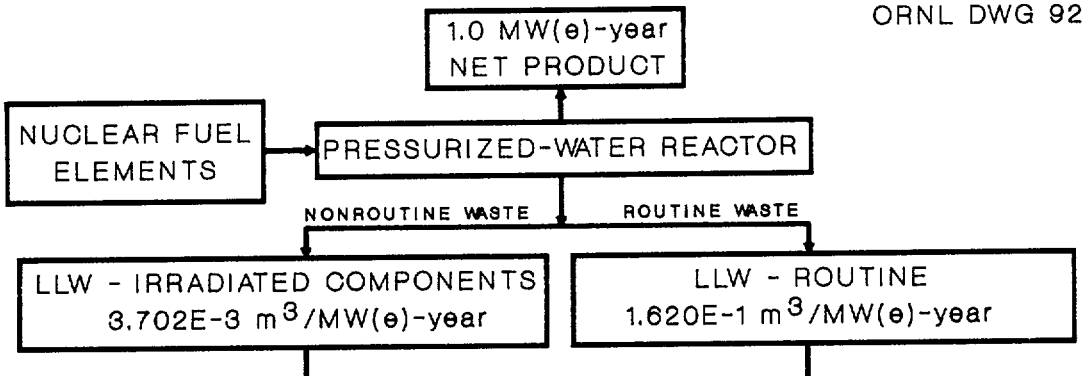
ISOTOPE	CI/MW(e)-year
^{3}H	1.682E-1
^{14}C	5.340E-4
^{51}Cr	4.818E-2
^{54}Mn	5.182E-1
^{55}Fe	4.839E+0
^{58}Co	1.170E-1
^{59}Fe	8.492E-3
^{59}Ni	3.195E-2
^{60}Co	6.688E+0
^{63}Ni	5.061E-1
^{65}Zn	1.354E-1
^{90}Sr	1.989E-5
^{90}Y	1.989E-5
^{94}Nb	5.246E-6
^{99}Tc	1.081E-4
^{129}I	3.381E-5
^{134}Cs	2.230E-3
^{137}Cs	7.311E-2
^{137m}Ba	6.921E-2
^{241}Pu	1.121E-4
^{242}Cm	1.080E-4
TOTAL	1.321E+1

ISOTOPE	CI/MW(e)-year
^{3}H	2.819E-3
^{14}C	3.828E-3
^{51}Cr	1.505E-1
^{54}Mn	1.304E-1
^{55}Fe	2.714E-1
^{58}Co	3.312E-2
^{59}Fe	8.218E-3
^{59}Ni	1.052E-4
^{60}Co	5.822E-1
^{63}Ni	1.338E-2
^{65}Zn	1.642E-1
^{90}Sr	6.816E-4
^{90}Y	6.816E-4
^{94}Nb	3.781E-6
^{99}Tc	4.316E-5
^{129}I	4.105E-4
^{134}Cs	7.333E-2
^{137}Cs	8.985E-2
^{137m}Ba	8.498E-2
^{144}Ce	3.664E-4
^{144}Pr	3.664E-4
^{241}Pu	6.751E-4
^{242}Cm	1.232E-5
TOTAL	1.612E+0

NOTE:
NET PRODUCT IS THE ELECTRICAL ENERGY LEAVING THE PLANT FOR DISTRIBUTION

Fig. C.6. Principal waste and product streams from a boiling-water reactor.

ORNL DWG 92-5860



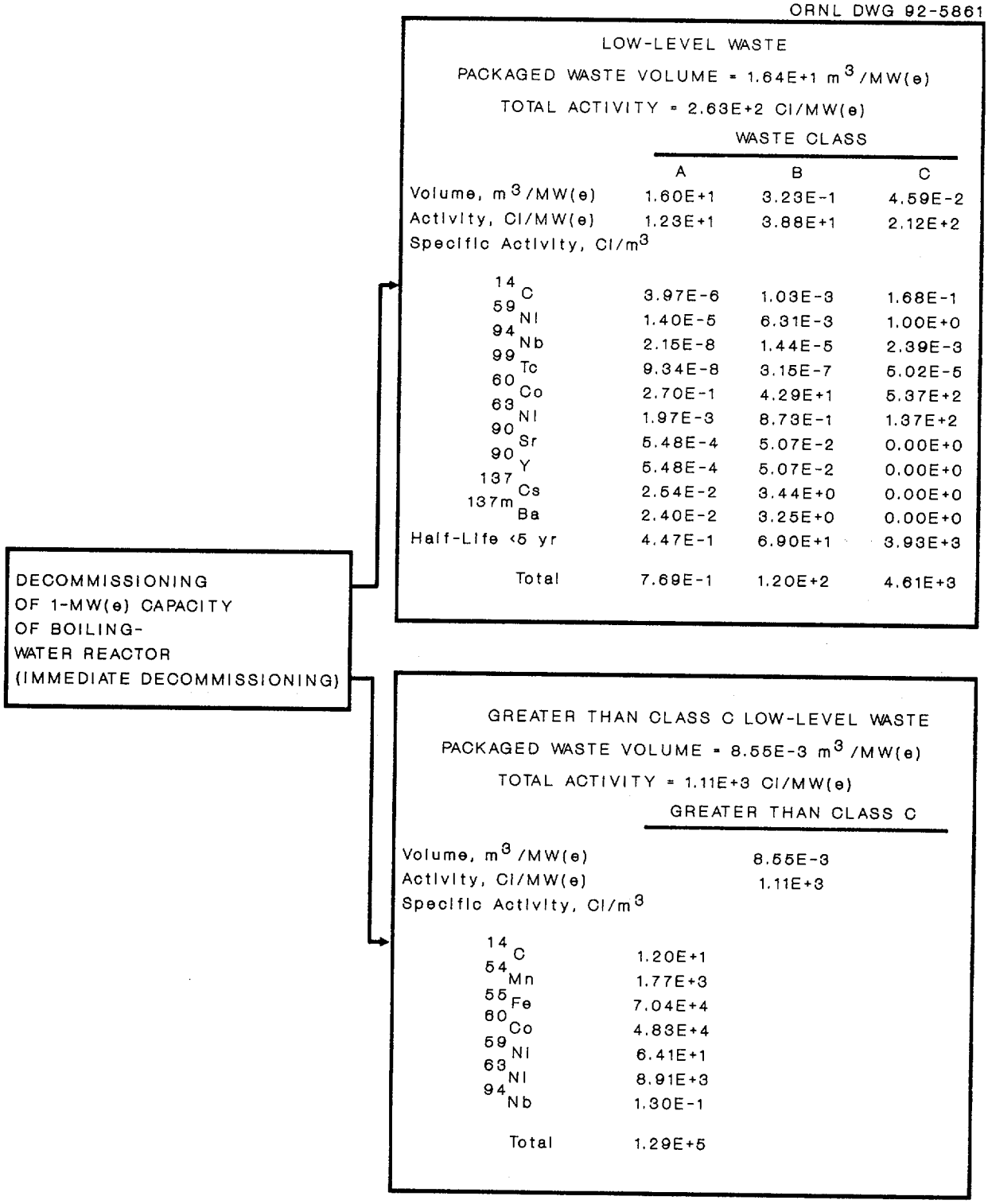
ISOTOPE	Ci/MW(e)-year
^{3}H	6.307E-3
^{14}C	7.794E-5
^{51}Cr	2.103E-2
^{54}Mn	8.410E-2
^{55}Fe	7.550E-1
^{58}Co	1.795E-1
^{59}Fe	1.553E-3
^{59}Ni	5.512E-4
^{60}Co	1.112E-0
^{63}Ni	1.400E-1
^{65}Zn	1.920E-7
^{90}Sr	1.883E-5
^{90}Y	1.883E-5
^{94}Nb	2.463E-8
^{99}Tc	5.649E-8
^{134}Cs	2.462E-2
^{137}Cs	4.225E-2
^{137m}Ba	3.996E-2
^{144}Ce	9.799E-8
^{144}Pr	9.799E-8
^{241}Pu	1.991E-6
TOTAL	2.407E+0

ISOTOPE	Ci/MW(e)-year
^{3}H	1.159E-2
^{14}C	8.729E-4
^{51}Cr	1.942E-3
^{54}Mn	1.207E-2
^{55}Fe	3.784E-2
^{58}Co	9.451E-2
^{59}Fe	2.853E-4
^{59}Ni	1.806E-4
^{60}Co	1.423E-1
^{63}Ni	6.392E-2
^{65}Zn	6.836E-5
^{90}Sr	2.272E-2
^{90}Y	2.272E-2
^{94}Nb	1.240E-6
^{99}Tc	3.935E-5
^{129}I	8.469E-6
^{134}Cs	5.599E-2
^{137}Cs	7.179E-2
^{137m}Ba	6.788E-2
^{144}Ce	3.186E-4
^{144}Pr	3.186E-4
^{241}Pu	3.965E-4
^{242}Cm	6.155E-4
TOTAL	6.084E-1

NOTE:
NET PRODUCT IS THE ELECTRICAL ENERGY LEAVING THE PLANT FOR DISTRIBUTION.

Fig. C.7. Principal waste and product streams from a pressurized-water reactor.

ORNL DWG 92-5861



LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 1.64E+1 m^3/MW(e)

TOTAL ACTIVITY = 2.63E+2 Ci/MW(e)

	WASTE CLASS		
	A	B	C
Volume, m^3/MW(e)	1.60E+1	3.23E-1	4.59E-2
Activity, Ci/MW(e)	1.23E+1	3.88E+1	2.12E+2
Specific Activity, Ci/m^3			
^{14}C	3.97E-6	1.03E-3	1.68E-1
^{59}Ni	1.40E-5	6.31E-3	1.00E+0
^{94}Nb	2.15E-8	1.44E-5	2.39E-3
^{99}Tc	9.34E-8	3.15E-7	5.02E-5
^{60}Co	2.70E-1	4.29E+1	5.37E+2
^{63}Ni	1.97E-3	8.73E-1	1.37E+2
^{90}Sr	5.48E-4	5.07E-2	0.00E+0
^{90}Y	5.48E-4	5.07E-2	0.00E+0
^{137}Cs	2.54E-2	3.44E+0	0.00E+0
^{137m}Ba	2.40E-2	3.25E+0	0.00E+0
Half-Life <5 yr	4.47E-1	6.90E+1	3.93E+3
Total	7.69E-1	1.20E+2	4.61E+3

GREATER THAN CLASS C LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 8.55E-3 m^3/MW(e)

TOTAL ACTIVITY = 1.11E+3 Ci/MW(e)

	GREATER THAN CLASS C
Volume, m^3/MW(e)	8.55E-3
Activity, Ci/MW(e)	1.11E+3
Specific Activity, Ci/m^3	
^{14}C	1.20E+1
^{54}Mn	1.77E+3
^{55}Fe	7.04E+4
^{60}Co	4.83E+4
^{59}Ni	6.41E+1
^{63}Ni	8.91E+3
^{94}Nb	1.30E-1
Total	1.29E+5

Fig. C.8. Boiling-water reactor decommissioning wastes per 1-MW(e) capacity.

ORNL DWG 92-5862

DECOMMISSIONING OF 1-MW(e) CAPACITY OF PRESSURIZED WATER REACTOR (IMMEDIATE DECOMMISSIONING)

LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 1.55E+1 m^3/MW(e)

TOTAL ACTIVITY = 1.06E+2 Ci/MW(e)

	WASTE CLASS		
	A	B	C
Volume, m^3/MW(e)	1.53E+1	1.82E-1	1.45E-2
Activity, Ci/MW(e)	3.28E+1	4.40E+1	2.91E+1
Specific Activity, Ci/m^3			
^{14}C	0.00E+0	0.00E+0	0.00E+0
^{59}Ni	4.75E-5	7.23E-3	5.51E-1
^{94}Nb	2.41E-8	5.22E-5	4.06E-3
^{99}Tc	0.00E+0	0.00E+0	0.00E+0
^{60}Co	3.57E-1	7.83E+1	7.39E+2
^{63}Ni	5.66E-3	1.16E+0	8.99E+1
^{90}Sr	4.88E-5	1.73E-3	0.00E+0
^{90}Y	4.88E-5	1.73E-3	0.00E+0
^{137}Cs	5.39E-2	2.06E+0	0.00E+0
^{137m}Ba	5.10E-2	1.95E+0	0.00E+0
Half-Life <5 yr	1.68E+0	1.59E+2	1.18E+3
Total	2.15E+0	2.42E+2	2.01E+3

GREATER THAN CLASS C LOW-LEVEL WASTE

PACKAGED WASTE VOLUME = 3.87E-3 m^3/MW(e)

TOTAL ACTIVITY = 5.05E+3 Ci/MW(e)

	GREATER THAN CLASS C
Volume, m^3/MW(e)	3.87E-3
Activity, Ci/MW(e)	5.05E+3
Specific Activity, Ci/m^3	
^{14}C	1.33E+2
^{54}Mn	7.73E+4
^{55}Fe	7.56E+5
^{60}Co	3.89E+5
^{59}Ni	4.31E+2
^{63}Ni	8.26E+4
^{94}Nb	2.24E+0
Total	1.31E+6

Fig. C.9. Pressurized-water reactor decommissioning wastes per 1-MW(e) capacity.

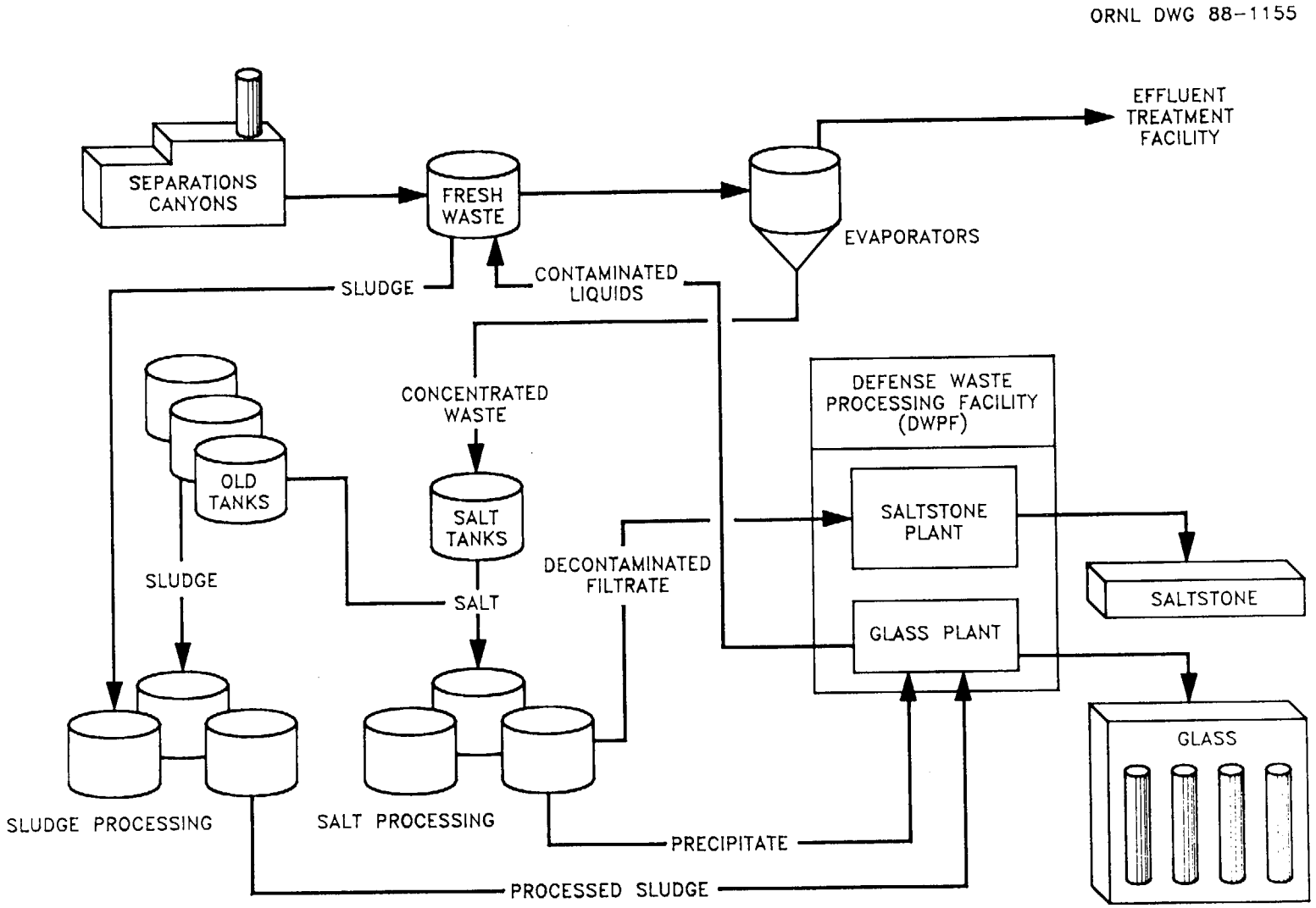


Fig. C.10. Waste flow diagram for the SRS Defense Waste Processing Facility.

Table C.1. Estimated representative unit activity and thermal power characteristics of various types of radioactive materials and wastes

Radioactive material/ waste type	Unit activity (Ci/m^3)	Unit thermal power (W/m^3)
Spent fuel[a]		
BWR	1,000,000-10,000,000	3,500-40,000
PWR	2,000,000-20,000,000	7,500-65,000
High-level waste	1,500-15,000	5-50
Transuranic waste		
Remote handled, stored	1,000	1-2
Contact handled, stored	25-50	0.5-1.5
Buried	0.25-0.50	0.005-0.010
Low-level waste[b]		
DOE sites	9-27	0.012-0.054
Commercial sites[c]	4.6-6.4	0.30-1.60
Class A	0.5-0.7	0.03-0.10
Class B	55-60	14-15
Class C	0.1->7,000[d]	0.003-115[d]
GTCC[e]	>0.1-No limit	>0.003-No limit
Uranium mill tailings	0.010	0.00020

[a]Lower-bound levels are based on cumulative spent fuel discharged; upper-bound levels are based on annual discharges.

[b]Based on 1986-1988 Solid Waste Information Management System (SWIMS) and the national Low-Level Waste Management Program (LLWMP) data access system, both of which were maintained by EG&G, Idaho, Inc., Idaho Falls, Idaho.

[c]Waste classification is defined by the NRC in 10 CFR 61.55 on the basis of concentration of certain long- and short-lived radionuclides. The classification system is designed to minimize potential exposures in both the short and long term. The gross Ci/m^3 shown above are representative of typical LLW shipped to commercial disposal sites. Most medical wastes are Class A. The nuclear power plant wastes account for most of the radioactivity, but some industrial wastes are in the Class B and C categories.

[d]Maximum for ^{63}Ni in activated metal or ^{90}Sr. There is no limit on concentration of ^{3}H, ^{60}Co, or nuclides with half-lives <5 years. The maximum thermal power shown is based on the highest reported gross Ci/m^3 analysis for irradiated core components (1986-1988) and assumes all the activity is due to ^{60}Co, which would yield the greatest heat output. If the activity is due to activation products, such as ^{54}Mn, ^{58}Co, etc., the Ci/m^3 could be much higher for individual shipments and the total W/m^3 could exceed the value shown.

[e]In temporary storage. The concentration of actinides and ^{129}I determine the lower activity boundary. There is no limit on concentration of ^{3}H, ^{60}Co, or nuclides with half-lives <5 years.

Table C.2. Basic factors used for fuel cycle, DOE waste, and I/I waste projections[a]

Activity/facility	Waste type	Annual waste volume generation rate
Electric power generation		Per unit energy generated [m^3/GW(e)-year]
Boiling-water reactor	LLW (routine)	449.7
	LLW (nonroutine)	16.68
Pressurized-water reactor	LLW (routine)	162.0
	LLW (nonroutine)	3.702
Nuclear fuel cycle support[b]		
Uranium mill	Mill tailings	118,000
Uranium conversion[c]	LLW	10.403
Uranium enrichment[d]	LLW	3.52
Fuel fabrication	LLW	87.36
DOE wastes		Annual increase in waste volume inventory during 1991 (m^3/year)
	LLW	53,520
	TRU	1,888
	HLW	-2,500[e]
Industrial/institutional wastes		Annual increase in waste volume inventory during 1991 (m^3/year)
	LLW	8,194

[a]Volumes given are typical for each operation. Many fuel cycle operations occur years before or after electricity from the nuclear reactor is generated.

[b]Waste quantities for the case of no spent fuel recycle and based on a ratio of PWRs to BWRs of 2 to 1.

[c]Assumes one-half of conversion demand is met by direct fluorination and the remaining half of demand is met by solvent extraction-fluorination.

[d]Assumes enrichment demand is met by gaseous diffusion.

[e]This is the difference between the total HLW in storage through 1991 (reported in Table 2.5) and the total HLW in storage through 1990 (reported in Table 2.5 of ref. 4). Such a quantity represents the annual change to all forms of HLW in storage. The negative number listed represents a net annual volume decrease that results from combined changes in both the annual rate of waste generation and waste management operations such as evaporation and calcination.

Table C.3. Lifetime radioactive waste generation by light-water reactors and supporting fuel cycle activities

Waste type	Reference BWR, 1 GW(e)		Reference PWR, 1 GW(e)	
	Volume (m^3)	Radioactivity (undecayed curies)	Volume (m^3)	Radioactivity (undecayed curies)
1. Fuel cycle wastes (no reprocessing)[a]				
A. Mill tailings	3.007E+06	2.353E+04	3.098E+06	2.424E+04
B. LLW from uranium conversion[b]	2.651E+02	2.975E+03	2.732E+02	3.066E+03
C. LLW from uranium enrichment[c]	8.502E+01	3.355E+03	9.479E+01	3.457E+03
D. LLW from fuel fabrication	2.511E+03	5.974E+00	2.151E+03	5.118E+00
2. LLW from reactor power generation[a]				
A. Routine wastes	1.169E+04	4.191E+04	4.212E+03	1.582E+04
B. Nonroutine wastes	4.337E+02	3.435E+05	9.625E+01	6.258E+04
3. Reactor spent fuel[a]	4.792E+02[d]	1.945E+09[e]	3.511E+02[d]	2.188E+09[e]
4. Decommissioning wastes				
A. LLW	1.640E+04	2.631E+05	1.548E+04	1.061E+05
B. Greater-than-Class-C LLW	8.553E+00	1.107E+06	3.870E+00	5.051E+06
Totals	3.039E+06	1.947E+09	3.121E+06	2.193E+09

[a]Waste generated from 40 years of reactor operation and 26 GW(e)-years of electric energy production.

[b]Assumes one-half of conversion demand will be met by direct fluorination and the remaining half by solvent extraction-fluorination.

[c]Applies to the gaseous diffusion process.

[d]Includes spacing between the stacked fuel rods of each assembly.

[e]Based on activity levels measured 1 year after reactor discharge, as reported in ref. 5 from using the ORIGEN2 code (ref. 6). Activity levels reported for the BWR are based on a burnup of 27,500 MWd/MTIHM. For the PWR, these levels are based on a burnup of 33,000 MWd/MTIHM.

Table C.4. Mass, radioactivity, and thermal power of nuclides in domestic commercial LWR spent fuel at the end of calendar year 1991[a]

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1	Hydrogen	Stable[b]	8.74E+03	1.13E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Hydrogen	3	1.57E+02	1.22E+03	1.52E+06	1.18E+07	5.11E+01	3.98E+02
2	Helium	Stable	5.10E+03	5.33E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Lithium	Stable	2.09E+03	2.59E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Beryllium	Stable	1.96E+00	2.08E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Boron	Stable	1.92E+03	2.36E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Carbon	Stable	3.41E+05	4.25E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Carbon	14	8.37E+02	8.82E+03	3.73E+03	3.93E+04	1.09E+00	1.15E+01
7	Nitrogen	Stable	2.34E+05	2.93E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Oxygen	Stable	2.58E+08	3.19E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Fluorine	Stable	2.05E+04	2.53E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Neon	Stable	8.19E-01	8.78E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Sodium	Stable	2.86E+04	3.54E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Sodium	24	1.69E-04	1.69E-04	1.47E+03	1.47E+03	4.08E+01	4.08E+01
12	Magnesium	Stable	3.90E+03	4.81E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Aluminum	Stable	1.61E+05	1.92E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Silicon	Stable	9.11E+05	1.13E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Phosphorus	Stable	4.55E+05	5.28E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Phosphorus	32	3.07E-01	3.07E-01	8.77E+04	8.77E+04	8.89E+02	8.89E+02
16	Sulfur	Stable	5.00E+04	6.36E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Chlorine	Stable	9.43E+03	1.18E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Argon	Stable	7.81E+02	8.44E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Potassium	Stable	3.37E+00	3.62E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Calcium	Stable	3.82E+03	4.73E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Scandium	Stable	2.20E-01	2.36E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Titanium	Stable	1.66E+05	1.96E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Vanadium	Stable	3.40E+04	3.95E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Vanadium	50	1.09E+02	1.22E+03	1.94E-11	2.19E-10	2.14E-13	2.41E-12
24	Chromium	Stable	2.09E+07	2.59E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Chromium	51	7.64E+01	7.64E+01	7.06E+06	7.07E+06	1.51E+03	1.51E+03
25	Manganese	Stable	1.73E+06	2.17E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Manganese	54	1.68E+02	3.06E+02	1.30E+06	2.37E+06	6.47E+03	1.18E+04
26	Iron	Stable	6.33E+07	7.89E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iron	55	4.53E+03	1.66E+04	1.13E+07	4.15E+07	3.82E+02	1.40E+03
	Iron	59	2.85E+00	2.86E+00	1.40E+05	1.41E+05	1.09E+03	1.09E+03
27	Cobalt	Stable	1.53E+05	1.87E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cobalt	58	8.85E+01	9.14E+01	2.82E+06	2.91E+06	1.69E+04	1.74E+04
	Cobalt	60	1.29E+04	7.00E+04	1.46E+07	7.92E+07	2.25E+05	1.22E+06
28	Nickel	Stable	1.99E+07	2.39E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Nickel	59	1.20E+05	1.21E+06	9.10E+03	9.20E+04	3.61E-01	3.65E+00
	Nickel	63	2.08E+04	1.99E+05	1.29E+06	1.23E+07	1.30E+02	1.24E+03
29	Copper	Stable	3.41E+04	4.17E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Zinc	Stable	7.71E+04	9.53E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zinc	65	2.02E+01	3.21E+01	1.67E+05	2.65E+05	5.83E+02	9.26E+02

Table C.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
31	Gallium	Stable	6.46E+01	6.94E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Germanium	Stable	1.19E+03	1.23E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Arsenic	Stable	3.73E+02	3.87E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Selenium	Stable	9.26E+04	9.50E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Selenium	79	1.11E+04	1.14E+05	7.72E+02	7.94E+03	1.92E-01	1.98E+00
35	Bromine	Stable	4.03E+04	4.15E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Krypton	Stable	6.33E+05	6.48E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Krypton	81	4.38E-02	4.34E-01	9.21E-04	9.13E-03	1.13E-07	1.13E-06
	Krypton	85	4.35E+04	3.14E+05	1.71E+07	1.23E+08	2.56E+04	1.85E+05
37	Rubidium	Stable	1.85E+05	1.88E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Rubidium	86	3.10E+00	3.10E+00	2.52E+05	2.52E+05	1.14E+03	1.14E+03
	Rubidium	87	4.58E+05	4.69E+06	4.01E-02	4.10E-01	3.35E-05	3.43E-04
38	Strontium	Stable	6.57E+05	6.71E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Strontium	89	9.75E+03	9.83E+03	2.84E+08	2.86E+08	9.80E+05	9.88E+05
	Strontium	90	9.93E+05	8.84E+06	1.35E+08	1.21E+09	1.57E+05	1.40E+06
39	Yttrium	Stable	8.08E+05	8.14E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Yttrium	90	2.52E+02	2.22E+03	1.37E+08	1.21E+09	7.60E+05	6.69E+06
	Yttrium	91	1.77E+04	1.80E+04	4.34E+08	4.41E+08	1.56E+06	1.58E+06
40	Zirconium	Stable	6.40E+08	8.33E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zirconium	93	1.56E+06	1.61E+07	3.91E+03	4.04E+04	4.54E-01	4.69E+00
	Zirconium	95	3.32E+04	3.39E+04	7.13E+08	7.29E+08	3.61E+06	3.69E+06
41	Niobium	Stable	1.03E+06	1.20E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Niobium	93m	1.24E+00	4.31E+01	3.50E+02	1.22E+04	6.19E-02	2.16E+00
	Niobium	94	1.25E+04	1.25E+05	2.34E+03	2.34E+04	2.38E+01	2.38E+02
	Niobium	95	2.83E+04	2.92E+04	1.11E+09	1.14E+09	5.30E+06	5.47E+06
	Niobium	95m	1.44E+01	1.47E+01	5.49E+06	5.61E+06	7.63E+03	7.79E+03
42	Molybdenum	Stable	6.78E+06	7.01E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Technetium	99	1.46E+06	1.52E+07	2.48E+04	2.57E+05	1.24E+01	1.29E+02
44	Ruthenium	Stable	4.11E+06	4.21E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ruthenium	103	1.32E+04	1.32E+04	4.27E+08	4.27E+08	1.43E+06	1.43E+06
	Ruthenium	106	2.29E+05	4.59E+05	7.67E+08	1.54E+09	4.56E+04	9.14E+04
45	Rhodium	Stable	7.95E+05	8.42E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Rhodium	103m	1.18E+01	1.18E+01	3.85E+08	3.86E+08	8.86E+04	8.87E+04
	Rhodium	106	2.15E-01	4.32E-01	7.67E+08	1.54E+09	7.36E+06	1.47E+07
46	Palladium	Stable	1.93E+06	1.93E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Palladium	107	4.23E+05	4.36E+06	2.18E+02	2.24E+03	1.29E-02	1.33E-01
47	Silver	Stable	1.46E+05	1.53E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Silver	108	1.50E-09	1.62E-08	1.10E+00	1.19E+01	4.10E-03	4.43E-02
	Silver	108m	4.74E-01	5.13E+00	1.24E+01	1.34E+02	1.20E-01	1.30E+00
	Silver	110	1.66E-05	2.60E-05	6.91E+04	1.09E+05	4.96E+02	7.80E+02
	Silver	110m	1.09E+03	1.72E+03	5.19E+06	8.17E+06	8.67E+04	1.36E+05
	Silver	111	2.50E+01	2.50E+01	3.95E+06	3.95E+06	8.85E+03	8.85E+03
48	Cadmium	Stable	2.54E+05	2.68E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cadmium	109	7.06E-01	1.67E+00	1.82E+03	4.32E+03	2.12E-01	5.01E-01
	Cadmium	113m	4.81E+02	3.77E+03	1.04E+05	8.19E+05	1.76E+02	1.38E+03

Table C.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
	Cadmium	115m	2.24E+01	2.25E+01	5.72E+05	5.74E+05	2.13E+03	2.14E+03
49	Indium	Stable	2.21E+03	2.47E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Indium	114	6.67E-05	6.72E-05	9.19E+04	9.25E+04	4.38E+02	4.40E+02
	Indium	114m	4.15E+00	4.18E+00	9.60E+04	9.66E+04	1.35E+02	1.36E+02
	Indium	115	4.41E+03	5.30E+04	2.75E-08	3.30E-07	3.94E-11	4.73E-10
	Indium	115m	4.47E-02	4.47E-02	2.83E+05	2.83E+05	5.65E+02	5.65E+02
50	Tin	Stable	1.05E+07	1.37E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Tin	117m	1.44E+01	1.44E+01	1.15E+06	1.15E+06	2.13E+03	2.13E+03
	Tin	119m	2.91E+03	4.60E+03	1.30E+07	2.06E+07	6.74E+03	1.07E+04
	Tin	121m	4.35E+01	4.29E+02	2.57E+03	2.54E+04	5.16E+00	5.08E+01
	Tin	123	4.07E+02	4.82E+02	3.35E+06	3.96E+06	1.05E+04	1.24E+04
	Tin	125	1.06E+01	1.06E+01	1.15E+06	1.15E+06	7.62E+03	7.62E+03
	Tin	126	5.17E+04	5.37E+05	1.47E+03	1.52E+04	1.83E+00	1.90E+01
51	Antimony	Stable	3.96E+04	4.18E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Antimony	124	3.36E+01	3.42E+01	5.89E+05	5.98E+05	7.82E+03	7.95E+03
	Antimony	125	2.83E+04	1.09E+05	2.93E+07	1.13E+08	9.14E+04	3.52E+05
	Antimony	126	1.30E+00	1.30E+00	1.09E+05	1.09E+05	2.01E+03	2.01E+03
	Antimony	127	1.11E+01	1.11E+01	2.95E+06	2.95E+06	1.75E+04	1.75E+04
52	Tellurium	Stable	8.84E+05	9.09E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Tellurium	123	2.12E+01	2.12E+02	6.18E-09	6.17E-08	6.26E-13	6.25E-12
	Tellurium	123m	2.06E+00	2.35E+00	1.83E+04	2.08E+04	2.66E+01	3.03E+01
	Tellurium	125m	3.82E+02	1.51E+03	6.89E+06	2.72E+07	5.79E+03	2.29E+04
	Tellurium	127	4.99E+00	5.47E+00	1.32E+07	1.44E+07	1.78E+04	1.95E+04
	Tellurium	127m	1.12E+03	1.26E+03	1.05E+07	1.18E+07	5.67E+03	6.37E+03
	Tellurium	129	3.57E-01	3.57E-01	7.47E+06	7.48E+06	2.67E+04	2.67E+04
	Tellurium	129m	3.67E+02	3.67E+02	1.11E+07	1.11E+07	1.94E+04	1.94E+04
	Tellurium	132	9.97E+01	9.97E+01	3.03E+07	3.03E+07	6.00E+04	6.00E+04
53	Iodine	Stable	1.02E+05	1.05E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iodine	129	3.40E+05	3.53E+06	6.00E+01	6.23E+02	2.78E-02	2.88E-01
	Iodine	131	4.41E+02	4.41E+02	5.47E+07	5.47E+07	1.86E+05	1.86E+05
54	Xenon	Stable	9.85E+06	1.01E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Xenon	129m	3.06E-03	3.06E-03	3.87E+02	3.87E+02	5.42E-01	5.42E-01
	Xenon	131m	1.78E+01	1.78E+01	1.49E+06	1.49E+06	1.43E+03	1.43E+03
	Xenon	133	4.37E+02	4.37E+02	8.18E+07	8.18E+07	8.76E+04	8.76E+04
55	Cesium	Stable	2.11E+06	2.19E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cesium	134	1.92E+05	5.83E+05	2.49E+08	7.55E+08	2.53E+06	7.68E+06
	Cesium	135	6.13E+05	6.08E+06	7.06E+02	7.00E+03	2.36E-01	2.34E+00
	Cesium	136	6.19E+01	6.19E+01	4.54E+06	4.54E+06	6.19E+04	6.19E+04
	Cesium	137	2.24E+06	2.01E+07	1.95E+08	1.75E+09	2.16E+05	1.93E+06
56	Barium	Stable	2.59E+06	2.62E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Barium	136m	2.78E-06	2.78E-06	7.48E+05	7.48E+05	9.04E+03	9.04E+03
	Barium	137m	3.43E-01	3.07E+00	1.85E+08	1.65E+09	7.25E+05	6.49E+06
	Barium	140	1.96E+03	1.96E+03	1.43E+08	1.43E+08	4.00E+05	4.00E+05
57	Lanthanum	Stable	2.30E+06	2.36E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Lanthanum	138	1.05E+01	1.11E+02	2.02E-07	2.13E-06	1.48E-09	1.56E-08

Table C.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
	Lanthanum	140	2.98E+02	2.98E+02	1.66E+08	1.66E+08	2.78E+06	2.78E+06
58	Cerium	Stable	2.29E+06	2.34E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cerium	141	1.22E+04	1.22E+04	3.49E+08	3.49E+08	5.10E+05	5.11E+05
	Cerium	142	2.13E+06	2.18E+07	5.12E-02	5.24E-01	0.00E+00	0.00E+00
	Cerium	144	4.54E+05	7.84E+05	1.45E+09	2.50E+09	9.62E+05	1.66E+06
59	Praseodymium	Stable	2.04E+06	2.08E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Praseodymium	143	2.13E+03	2.13E+03	1.44E+08	1.44E+08	2.68E+05	2.68E+05
	Praseodymium	144	1.92E+01	3.31E+01	1.45E+09	2.50E+09	1.07E+07	1.84E+07
	Praseodymium	144m	9.59E-02	1.66E-01	1.74E+07	3.00E+07	5.96E+03	1.03E+04
60	Neodymium	Stable	5.05E+06	5.21E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Neodymium	144	2.06E+06	2.44E+07	2.44E-06	2.89E-05	0.00E+00	0.00E+00
	Neodymium	147	5.88E+02	5.88E+02	4.72E+07	4.72E+07	1.14E+05	1.14E+05
61	Promethium	147	2.37E+05	9.09E+05	2.20E+08	8.43E+08	7.89E+04	3.02E+05
	Promethium	148	6.27E+01	6.27E+01	1.03E+07	1.03E+07	7.94E+04	7.94E+04
	Promethium	148m	3.95E+02	3.96E+02	8.44E+06	8.46E+06	1.07E+05	1.07E+05
62	Samarium	Stable	8.13E+05	8.50E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Samarium	147	1.44E+05	3.30E+06	3.28E-03	7.50E-02	4.49E-05	1.03E-03
	Samarium	148	3.24E+05	3.12E+06	9.79E-08	9.41E-07	1.17E-09	1.12E-08
	Samarium	149	5.35E+03	6.50E+04	1.28E-09	1.56E-08	0.00E+00	0.00E+00
	Samarium	151	2.44E+04	2.63E+05	6.41E+05	6.92E+06	7.51E+01	8.12E+02
63	Europium	Stable	2.05E+05	2.08E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Europium	152	6.12E+01	4.92E+02	1.06E+04	8.52E+04	8.01E+01	6.44E+02
	Europium	154	7.27E+04	4.64E+05	1.96E+07	1.25E+08	1.76E+05	1.12E+06
	Europium	155	2.53E+04	1.30E+05	1.18E+07	6.04E+07	8.58E+03	4.39E+04
	Europium	156	4.16E+02	4.16E+02	2.29E+07	2.29E+07	2.37E+05	2.37E+05
64	Gadolinium	Stable	1.10E+06	1.52E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Gadolinium	152	6.51E+01	2.30E+03	1.42E-09	5.02E-08	1.85E-11	6.54E-10
	Gadolinium	153	1.69E+02	2.99E+02	5.96E+05	1.05E+06	5.39E+02	9.53E+02
65	Terbium	Stable	1.90E+04	2.21E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Terbium	160	1.57E+02	1.62E+02	1.78E+06	1.83E+06	1.45E+04	1.49E+04
	Terbium	161	1.28E+00	1.28E+00	1.50E+05	1.50E+05	3.01E+02	3.01E+02
81	Thallium	Stable	1.87E-09	1.79E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Thallium	206	6.21E-22	6.21E-22	1.35E-13	1.35E-13	1.22E-15	1.22E-15
	Thallium	207	5.02E-12	2.94E-10	9.56E-04	5.60E-02	2.81E-06	1.64E-04
	Thallium	208	7.43E-09	3.53E-07	2.19E+00	1.04E+02	5.15E-02	2.44E+00
	Thallium	209	1.37E-14	9.99E-14	5.59E-06	4.09E-05	9.29E-08	6.79E-07
82	Lead	Stable	1.89E+03	2.33E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Lead	204	2.63E+01	3.26E+02	3.30E-13	4.08E-12	5.08E-15	6.29E-14
	Lead	205	6.32E-02	6.78E-01	3.67E-06	3.95E-05	1.07E-10	1.15E-09
	Lead	209	1.78E-10	5.38E-10	8.11E-04	2.45E-03	9.33E-07	2.81E-06
	Lead	210	7.25E-08	9.76E-06	5.54E-06	7.45E-04	1.28E-09	1.73E-07
	Lead	211	3.88E-11	2.27E-09	9.58E-04	5.61E-02	2.87E-06	1.68E-04
	Lead	212	4.38E-06	2.08E-04	6.09E+00	2.89E+02	1.16E-02	5.50E-01
	Lead	214	1.29E-12	1.68E-10	4.24E-05	5.50E-03	1.35E-07	1.75E-05

Table C.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
83	Bismuth	Stable	7.66E+02	9.47E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Bismuth	208	1.02E-02	1.09E-01	4.77E-05	5.08E-04	7.51E-07	7.99E-06
	Bismuth	210	1.33E-05	1.33E-05	1.65E+00	1.65E+00	3.80E-03	3.80E-03
	Bismuth	210m	6.00E-02	6.45E-01	3.41E-05	3.66E-04	1.07E-06	1.15E-05
	Bismuth	211	2.29E-12	1.34E-10	9.58E-04	5.61E-02	3.82E-05	2.24E-03
	Bismuth	212	4.16E-07	1.97E-05	6.09E+00	2.89E+02	1.04E-01	4.92E+00
	Bismuth	213	1.34E-11	9.78E-11	2.59E-04	1.89E-03	1.09E-06	7.96E-06
	Bismuth	214	9.59E-13	1.24E-10	4.24E-05	5.50E-03	5.43E-07	7.05E-05
84	Polonium	210	8.42E-03	1.02E-02	3.79E+01	4.60E+01	1.21E+00	1.47E+00
	Polonium	211	2.81E-17	1.65E-15	2.68E-06	1.57E-04	1.21E-07	7.07E-06
	Polonium	212	2.20E-17	1.04E-15	3.90E+00	1.85E+02	2.07E-01	9.82E+00
	Polonium	213	2.01E-20	1.47E-19	2.53E-04	1.85E-03	1.28E-05	9.37E-05
	Polonium	214	1.73E-19	1.72E-17	5.55E-05	5.51E-03	2.57E-06	2.56E-04
	Polonium	215	3.25E-17	1.90E-15	9.58E-04	5.61E-02	4.28E-05	2.51E-03
	Polonium	216	1.75E-11	8.30E-10	6.08E+00	2.89E+02	2.49E-01	1.18E+01
	Polonium	218	1.50E-13	1.94E-11	4.24E-05	5.50E-03	1.53E-06	1.99E-04
85	Astatine	217	1.61E-16	1.18E-15	2.59E-04	1.89E-03	1.10E-05	8.08E-05
86	Radon	218	8.86E-18	8.86E-18	1.31E-05	1.31E-05	5.64E-07	5.64E-07
	Radon	219	7.36E-14	4.31E-12	9.58E-04	5.61E-02	3.98E-05	2.33E-03
	Radon	220	6.59E-09	3.13E-07	6.08E+00	2.89E+02	2.31E-01	1.10E+01
	Radon	222	2.75E-10	3.57E-08	4.24E-05	5.50E-03	1.40E-06	1.82E-04
87	Francium	221	1.46E-12	1.07E-11	2.59E-04	1.89E-03	9.99E-06	7.31E-05
	Francium	223	3.71E-13	2.03E-11	1.44E-05	7.87E-04	3.73E-08	2.04E-06
88	Radium	222	9.80E-15	9.80E-15	1.31E-05	1.31E-05	5.19E-07	5.19E-07
	Radium	223	1.87E-08	1.10E-06	9.58E-04	5.61E-02	3.41E-05	2.00E-03
	Radium	224	3.82E-05	1.81E-03	6.08E+00	2.89E+02	2.09E-01	9.92E+00
	Radium	225	6.03E-09	4.77E-08	2.36E-04	1.87E-03	1.66E-07	1.31E-06
	Radium	226	4.32E-05	5.57E-03	4.27E-05	5.51E-03	1.23E-06	1.59E-04
	Radium	228	2.42E-11	3.28E-09	5.66E-09	7.68E-07	4.36E-13	5.92E-11
89	Actinium	225	4.46E-09	3.26E-08	2.59E-04	1.89E-03	9.04E-06	6.61E-05
	Actinium	227	1.44E-05	7.88E-04	1.04E-03	5.70E-02	5.04E-07	2.76E-05
	Actinium	228	4.17E-12	4.51E-12	9.36E-06	1.01E-05	8.09E-08	8.75E-08
90	Thorium	226	4.88E-13	4.88E-13	1.31E-05	1.31E-05	5.01E-07	5.01E-07
	Thorium	227	3.17E-08	1.81E-06	9.75E-04	5.57E-02	3.56E-05	2.03E-03
	Thorium	228	7.32E-03	3.50E-01	6.01E+00	2.87E+02	1.96E-01	9.40E+00
	Thorium	229	9.56E-04	8.65E-03	2.03E-04	1.84E-03	6.22E-06	5.63E-05
	Thorium	230	2.78E+00	1.04E+02	5.61E-02	2.10E+00	1.59E-03	5.95E-02
	Thorium	231	6.93E-05	8.21E-04	3.69E+01	4.37E+02	2.07E-02	2.45E-01
	Thorium	232	4.51E-01	1.81E+01	4.95E-08	1.99E-06	1.20E-09	4.81E-08
	Thorium	233	9.07E-12	9.07E-12	3.31E-04	3.31E-04	8.39E-07	8.39E-07
	Thorium	234	2.63E-02	3.27E-01	6.09E+02	7.58E+03	2.47E-01	3.07E+00
91	Protactinium	231	5.39E-01	6.46E+00	2.55E-02	3.05E-01	7.67E-04	9.19E-03
	Protactinium	232	9.86E-06	9.86E-06	4.24E+00	4.24E+00	2.77E-02	2.77E-02
	Protactinium	233	2.83E-02	2.77E-01	5.88E+02	5.74E+03	1.34E+00	1.30E+01
	Protactinium	234	4.00E-07	4.93E-06	8.00E-01	9.86E+00	1.15E-02	1.42E-01

Table C.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
	Protactinium	234m	8.86E-07	1.10E-05	6.09E+02	7.58E+03	3.01E+00	3.75E+01
	Protactinium	235	5.99E-17	5.99E-17	1.99E-09	1.99E-09	5.55E-12	5.55E-12
92	Uranium	230	4.79E-10	4.79E-10	1.31E-05	1.31E-05	4.65E-07	4.65E-07
	Uranium	231	4.44E-09	4.44E-09	5.97E-04	5.97E-04	4.94E-07	4.94E-07
	Uranium	232	1.01E+00	1.81E+01	2.16E+01	3.87E+02	6.93E-01	1.24E+01
	Uranium	233	2.51E+00	4.16E+01	2.43E-02	4.03E-01	7.06E-04	1.17E-02
	Uranium	234	3.31E+05	3.99E+06	2.07E+03	2.50E+04	5.96E+01	7.19E+02
	Uranium	235	1.46E+07	1.99E+08	3.15E+01	4.31E+02	8.24E-01	1.13E+01
	Uranium	236	7.37E+06	7.59E+07	4.77E+02	4.91E+03	1.29E+01	1.33E+02
	Uranium	237	4.87E+02	4.88E+02	3.98E+07	3.98E+07	7.53E+04	7.54E+04
	Uranium	238	1.81E+09	2.25E+10	6.08E+02	7.58E+03	1.54E+01	1.92E+02
	Uranium	239	1.72E-02	1.72E-02	5.75E+05	5.75E+05	1.55E+03	1.55E+03
	Uranium	240	2.27E-04	2.27E-04	2.11E+02	2.11E+02	1.73E-01	1.73E-01
93	Neptunium	235	5.83E-03	1.18E-02	8.18E+00	1.66E+01	4.75E-04	9.62E-04
	Neptunium	236	7.31E-01	6.82E+00	9.64E-03	8.98E-02	1.94E-05	1.81E-04
	Neptunium	236m	8.69E-05	8.69E-05	5.13E+01	5.13E+01	4.06E-02	4.06E-02
	Neptunium	237	8.35E+05	8.14E+06	5.89E+02	5.74E+03	1.80E+01	1.76E+02
	Neptunium	238	1.97E+01	1.97E+01	5.11E+06	5.11E+06	2.45E+04	2.45E+04
	Neptunium	239	1.47E+03	1.47E+03	3.41E+08	3.41E+08	8.24E+05	8.25E+05
	Neptunium	240	3.66E-04	3.66E-04	4.42E+03	4.42E+03	4.68E+01	4.68E+01
	Neptunium	240m	2.03E-06	2.03E-06	2.15E+02	2.15E+02	1.25E+00	1.25E+00
	Neptunium	241	1.45E-13	1.45E-13	7.08E-06	7.08E-06	1.98E-08	1.98E-08
94	Plutonium	236	1.90E+00	6.86E+00	1.01E+03	3.65E+03	3.51E+01	1.27E+02
	Plutonium	237	1.67E-02	1.68E-02	2.02E+02	2.03E+02	7.45E-02	7.48E-02
	Plutonium	238	2.65E+05	2.39E+06	4.53E+06	4.10E+07	1.50E+05	1.36E+06
	Plutonium	239	9.52E+06	1.14E+08	5.92E+05	7.08E+06	1.83E+04	2.18E+05
	Plutonium	240	4.32E+06	4.67E+07	9.86E+05	1.06E+07	3.07E+04	3.31E+05
	Plutonium	241	2.32E+06	1.92E+07	2.39E+08	1.98E+09	7.42E+03	6.14E+04
	Plutonium	242	9.02E+05	8.96E+06	3.44E+03	3.42E+04	1.02E+02	1.01E+03
	Plutonium	243	1.82E-01	1.82E-01	4.75E+05	4.75E+05	5.48E+02	5.48E+02
	Plutonium	244	4.99E+01	4.62E+02	8.86E-04	8.19E-03	2.57E-05	2.38E-04
	Plutonium	245	1.91E-06	1.91E-06	2.31E+00	2.31E+00	5.48E-03	5.48E-03
	Plutonium	246	4.19E-07	4.19E-07	2.05E-02	2.05E-02	1.73E-05	1.73E-05
95	Americium	239	3.35E-09	3.35E-09	3.70E-03	3.70E-03	8.94E-06	8.94E-06
	Americium	240	1.45E-05	1.45E-05	3.73E+00	3.73E+00	2.44E-02	2.44E-02
	Americium	241	1.19E+05	7.43E+06	4.07E+05	2.55E+07	1.35E+04	8.48E+05
	Americium	242	4.90E-01	6.28E-01	3.96E+05	5.08E+05	4.50E+02	5.76E+02
	Americium	242m	1.34E+03	1.29E+04	1.31E+04	1.25E+05	5.16E+00	4.94E+01
	Americium	243	1.78E+05	1.68E+06	3.56E+04	3.35E+05	1.14E+03	1.08E+04
	Americium	244	1.27E-02	1.27E-02	1.62E+04	1.62E+04	8.50E+01	8.50E+01
	Americium	244m	1.31E-04	1.31E-04	3.88E+03	3.88E+03	1.17E+01	1.17E+01
	Americium	245	4.50E-07	4.50E-07	2.78E+00	2.78E+00	5.16E-03	5.16E-03
	Americium	246	6.72E-10	6.72E-10	2.06E-02	2.06E-02	1.66E-04	1.66E-04

Table C.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
96	Curium	242	1.24E+04	1.59E+04	4.11E+07	5.25E+07	1.51E+06	1.93E+06
	Curium	243	6.87E+02	5.47E+03	3.55E+04	2.83E+05	1.30E+03	1.04E+04
	Curium	244	5.21E+04	3.83E+05	4.22E+06	3.10E+07	1.48E+05	1.08E+06
	Curium	245	1.99E+03	1.74E+04	3.41E+02	2.99E+03	1.13E+01	9.93E+01
	Curium	246	2.66E+02	2.21E+03	8.16E+01	6.79E+02	2.67E+00	2.22E+01
	Curium	247	2.68E+00	2.12E+01	2.49E-04	1.97E-03	7.94E-06	6.29E-05
	Curium	248	1.53E-01	1.13E+00	6.49E-04	4.83E-03	8.08E-05	6.01E-04
	Totals		2.93E+09	3.66E+10	1.09E+10	2.32E+10	4.50E+07	8.76E+07

[a]Includes contributions from nuclides in the fuel, cladding, and fuel assembly structural material.
[b]The term "stable" represents a group of nonradioactive nuclides of a particular element.

Table C.5. Representative DOE LLW radionuclide composition by percent activity[a]

Uranium/thorium		Fission product		Induced activity		Alpha, <100 nCi/g		"Other"	
Nuclide	Composition	Nuclide	Composition	Nuclide	Composition	Nuclide	Composition	Nuclide	Composition
^{208}Tl	0.0017	^{60}Co	0.08	^{51}Cr	4.95	^{238}Pu	2.62	^{3}H	1.22
^{212}Pb	0.0045	^{90}Sr	7.77	^{54}Mn	38.10	^{239}Pu	0.20	^{14}C	0.06
^{212}Bi	0.0045	^{90}Y	7.77	^{58}Co	55.40	^{240}Pu	0.70	^{54}Mn	6.76
^{212}Po	0.0029	^{95}Zr	1.27	^{59}Fe	0.49	^{241}Pu	96.4	^{58}Co	6.24
^{216}Po	0.0045	^{95}Nb	2.83	^{60}Co	0.87	^{241}Am	0.004	^{60}Co	18.03
^{224}Ra	0.0045	^{99}Tc	0.02	^{65}Zn	0.19	^{242}Cm	0.056	^{90}Sr	8.48
^{228}Ra	0.0269	^{125}Sb	2.93			^{244}Cm	0.020	^{90}Y	8.48
^{228}Ac	0.0269	^{125m}Te	0.73		100.00			^{99}Tc	0.12
^{228}Th	0.0045	^{106}Ru	6.39				100.000	^{134}Cs	13.98
^{231}Th	0.0259	^{106}Rh	6.39					^{137}Cs	18.45
^{232}Th	0.273	^{134}Cs	0.38					^{137m}Ba	17.45
^{234}Th	33.197	^{137}Cs	17.31					^{238}U	0.73
^{234m}Pa	33.197	^{137m}Ba	16.38						100.00
^{234}Pa	0.0034	^{144}Ce	14.67						
^{235}U	0.0258	^{144}Pr	14.67						
^{238}U	33.197	^{147}Pm	0.06						
	100.0000	^{151}Sm	0.11						
		^{152}Eu	0.09						
		^{154}Eu	0.09						
		^{155}Eu	0.06						
			100.00						

[a]Based on ref. 1.

Table C.6. Average concentrations for representative radionuclides in LLW at commercial disposal sites[a]

Radionuclide	Half-life[b]	Concentration (Ci/m^3)
^{3}H	1.228E+01 y	1.083E+00
^{14}C	5.730E+03 y	5.079E-03
^{26}Al	7.300E+05 y	2.980E-10
^{32}Si	1.000E+02 y	3.725E-11
^{32}P	1.428E+01 d	9.292E-04
^{35}S	8.751E+01 d	2.208E-03
^{36}Cl	3.010E+05 y	6.143E-06
^{40}K	1.280E+09 y	1.766E-07
^{51}Cr	2.770E+01 d	7.137E-02
^{54}Mn	3.122E+02 d	3.895E-01
^{55}Fe	2.730E+00 y	3.112E+00
^{59}Fe	4.445E+01 d	5.081E-03
^{58}Co	7.092E+01 d	2.047E-01
^{60}Co	5.271E+00 y	2.242E+00
^{59}Ni	7.500E+04 y	1.364E-03
^{63}Ni	1.001E+02 y	2.692E-01
^{65}Zn	2.441E+02 d	1.174E-01
^{85}Kr	1.072E+01 y	8.147E-04
^{89}Sr	5.055E+01 d	6.032E-03
^{90}Sr	2.850E+01 y	6.987E-02
^{90}Y	2.671E+01 d	6.987E-02
^{91}Y	5.851E+01 d	8.859E-03
^{95}Zr	6.402E+01 d	1.036E-02
^{94}Nb	2.030E+04 y	1.659E-05
^{95}Nb	3.497E+01 d	1.916E-02
^{93}Mo	3.500E+03 y	9.273E-12
^{99}Tc	2.130E+05 y	1.949E-04
^{103}Ru	3.925E+01 d	5.900E-04
^{108m}Ag	1.300E+02 y	5.534E-06
^{110m}Ag	2.498E+02 d	3.600E-02
^{113}Cd	9.000E+15 y	4.223E-12
^{124}Sb	6.020E+00 d	2.621E-03
^{125}Sb	2.730E+00 y	1.901E-02
^{123}Te	1.300E+13 y	5.710E-07
^{125}I	6.014E+00 d	4.570E-04
^{129}I	1.570E+07 y	2.101E-05
^{131}I	8.040E+00 d	5.299E-03
^{134}Cs	2.062E+00 y	8.661E-02
^{135}Cs	3.000E+06 y	1.105E-05
^{137}Cs	3.017E+01 y	2.431E-01
^{137m}Ba	2.552E+00 min	2.300E-01
^{141}Ce	3.250E+01 d	1.649E-03
^{144}Ce	2.849E+02 d	1.463E-02
^{144}Pr	1.728E+01 min	1.463E-02
^{144}Nd	2.100E+15 y	1.689E-10
^{147}Pm	2.623E+00 y	1.317E-02
^{157}Tb	1.100E+02 y	1.012E-10
^{158}Tb	1.800E+02 y	3.768E-10
^{175}Hf	7.000E+01 d	1.427E-03
^{181}Hf	4.240E+01 d	3.235E-03
^{187}Re	4.100E+10 y	1.772E-11

Table C.6 (continued)

Radionuclide	Half-life[b]	Concentration (Ci/m^3)
^{209}Po	3.253E+00 h	1.284E-10
^{226}Ra	1.600E+03 y	2.852E-04
^{229}Th	7.340E+03 y	1.310E-10
^{230}Th	7.540E+04 y	1.721E-08
^{232}Th	1.405E+10 y	8.171E-03
^{231}Pa	3.276E+04 y	1.016E-10
^{233}U	1.592E+05 y	2.308E-07
^{234}U	2.454E+05 y	5.368E-05
^{235}U	7.037E+08 y	2.541E-05
^{236}U	2.432E+07 y	7.886E-07
^{238}U	4.468E+09 y	6.992E-03
^{237}Np	2.140E+06 y	1.670E-07
^{239}Pu	2.413E+04 y	7.714E-06[c]
^{240}Pu	6.563E+03 y	1.892E-06[c]
^{242}Pu	3.763E+05 y	4.652E-07[c]
^{241}Am	4.322E+02 y	3.063E-05
^{243}Am	7.380E+03 y	1.056E-08
^{248}Cm	3.400E+05 y	4.700E-07
Others[d]	–	3.308E-03
Total		8.379E+00

[a]Taken from the report by G. W. Roles, Characteristics of Low-Level Radioactive Waste Disposed During 1987 Through 1989, NUREG-1418, December 1990.

[b]y = years; d = days; h = hours; min = minutes; and s = seconds.

[c]The commercial disposal site at Barnwell, South Carolina, has not permitted disposal of plutonium; thus, its isotopes are omitted when this list is applied to waste disposed at Barnwell.

[d]Includes contributions from radionuclides in natural thorium, natural and depleted uranium, and other actinides.

Table C.7. Projected chemical and radionuclide composition of saltstone at SRS[a,b]

End of calendar year	Fraction of radionuclide[c]										
	^{3}H	^{90}Sr	^{90}Y	^{99}Tc	^{106}Ru	^{106}Rh	^{125}Sb	^{137}Cs	^{137m}Ba	^{147}Pm	Total
1992	0.029	0.138	0.138	0.014	0.000	0.000	0.008	0.036	0.033	0.603	1.00
1993	0.026	0.115	0.115	0.020	0.001	0.001	0.021	0.030	0.027	0.644	1.00
1994	0.026	0.116	0.116	0.019	0.001	0.001	0.015	0.029	0.027	0.649	1.00
1995	0.029	0.127	0.127	0.020	0.001	0.001	0.012	0.032	0.030	0.622	1.00
1996	0.035	0.140	0.140	0.023	0.000	0.000	0.011	0.037	0.034	0.580	1.00
1997	0.041	0.153	0.153	0.025	0.001	0.001	0.010	0.040	0.036	0.541	1.00
1998	0.045	0.163	0.163	0.030	0.001	0.001	0.009	0.042	0.039	0.507	1.00
1999	0.050	0.175	0.175	0.032	0.000	0.000	0.008	0.042	0.039	0.477	1.00
2000	0.057	0.191	0.191	0.034	0.000	0.000	0.008	0.042	0.039	0.437	1.00
2001	0.063	0.209	0.209	0.036	0.000	0.000	0.008	0.043	0.040	0.391	1.00
2002	0.068	0.228	0.228	0.039	0.000	0.000	0.007	0.044	0.040	0.344	1.00
2003	0.074	0.247	0.247	0.041	0.000	0.000	0.007	0.045	0.041	0.298	1.00
2004	0.079	0.265	0.265	0.043	0.001	0.001	0.006	0.045	0.042	0.255	1.00
2005	0.083	0.281	0.281	0.044	0.001	0.001	0.006	0.046	0.042	0.215	1.00
2006	0.088	0.295	0.295	0.046	0.001	0.001	0.006	0.046	0.042	0.181	1.00
2007	0.091	0.308	0.308	0.047	0.001	0.001	0.006	0.045	0.042	0.152	1.00
2008	0.094	0.320	0.320	0.048	0.001	0.001	0.006	0.045	0.041	0.124	1.00
2009	0.097	0.331	0.331	0.049	0.001	0.001	0.005	0.044	0.041	0.101	1.00
2010	0.097	0.335	0.335	0.051	0.001	0.001	0.006	0.046	0.042	0.086	1.00
2011	0.100	0.343	0.343	0.054	0.000	0.000	0.004	0.047	0.043	0.065	1.00
2012	0.102	0.348	0.348	0.056	0.000	0.000	0.004	0.047	0.044	0.051	1.00
2013	0.103	0.351	0.351	0.058	0.000	0.000	0.003	0.048	0.044	0.041	1.00
2014	0.105	0.354	0.354	0.060	0.000	0.000	0.002	0.048	0.044	0.032	1.00
2015	0.108	0.355	0.355	0.061	0.000	0.000	0.002	0.048	0.045	0.025	1.00
2016	0.109	0.355	0.355	0.062	0.000	0.000	0.003	0.048	0.044	0.024	1.00
2017	0.111	0.355	0.355	0.063	0.000	0.000	0.003	0.047	0.044	0.022	1.00
2018	0.112	0.355	0.355	0.063	0.000	0.000	0.003	0.047	0.043	0.021	1.00
2019	0.113	0.355	0.355	0.064	0.000	0.000	0.004	0.046	0.043	0.020	1.00
2020	0.114	0.355	0.355	0.065	0.000	0.000	0.004	0.046	0.042	0.018	1.00
2021	0.116	0.355	0.355	0.066	0.000	0.000	0.004	0.045	0.042	0.017	1.00
2022	0.117	0.355	0.355	0.066	0.000	0.000	0.004	0.045	0.041	0.017	1.00
2023	0.118	0.354	0.354	0.067	0.000	0.000	0.004	0.044	0.041	0.016	1.00
2024	0.119	0.354	0.354	0.068	0.000	0.000	0.004	0.044	0.040	0.015	1.00
2025	0.121	0.354	0.354	0.069	0.000	0.000	0.004	0.043	0.040	0.014	1.00
2026	0.122	0.354	0.354	0.070	0.000	0.000	0.003	0.043	0.040	0.014	1.00
2027	0.123	0.354	0.354	0.071	0.000	0.000	0.003	0.043	0.039	0.013	1.00
2028	0.124	0.354	0.354	0.072	0.000	0.000	0.003	0.042	0.039	0.012	1.00
2029	0.126	0.353	0.353	0.073	0.000	0.000	0.003	0.042	0.038	0.012	1.00
2030	0.127	0.353	0.353	0.073	0.000	0.000	0.003	0.041	0.038	0.011	1.00

[a]Taken from ref. 3.

[b]Chemical composition (wt %): fly ash, 46.0; water, 30.2; cement, 11.5; $NaNO_3$, 6.0; NaOH, 1.9; $NaNO_2$, 1.5; $NaAl(OH)_4$, 1.3; Na_2SO_4, 0.7; and other, 0.9.

[c]The radionuclide composition at the end of a year is expressed in terms of the fraction of each significant nuclide making up an average unit of radioactivity in all the saltstone collected from the beginning of the operation of the saltstone plant to the end of the year indicated.

Table C.8. Historical and projected DOE/EIA No New Orders Case commercial LWR net annual electrical generation[a,b]

End of calendar year	Historical generation [MW(e)-years]			End of calendar year	No New Orders Case projected generation [MW(e)-years]		
	BWR	PWR	Total		BWR	PWR	Total
1960	29	4	33	1992	21,264	48,351	69,615
1961	60	97	157	1993	21,178	48,687	69,865
1962	137	96	233	1994	21,178	49,306	70,484
1963	136	208	344	1995	21,195	49,966	71,161
1964	164	198	362	1996	21,178	50,563	71,741
1965	164	212	376	1997	21,178	50,808	71,986
1966	221	334	556	1998	21,178	50,890	72,068
1967	184	419	603	1999	21,143	51,035	72,178
1968	205	781	986	2000	21,143	51,035	72,178
1969	238	1,049	1,287	2001	21,143	51,035	72,178
1970	1,011	1,192	2,203	2002	21,124	51,035	72,159
1971	1,969	2,103	4,075	2003	21,093	51,035	72,128
1972	3,188	2,450	5,641	2004	21,093	51,035	72,128
1973	4,446	4,620	9,073	2005	21,093	51,035	72,128
1974	5,298	6,650	11,955	2006	21,093	51,035	72,128
1975	6,309	12,089	17,395	2007	21,093	51,035	72,128
1976	8,044	13,113	21,343	2008	21,093	51,035	72,128
1977	9,636	17,737	27,388	2009	20,792	50,956	71,748
1978	11,353	19,596	31,142	2010	20,200	50,724	70,924
1979	11,390	17,332	28,662	2011	18,909	50,264	69,173
1980	10,416	17,848	28,343	2012	18,621	49,658	68,279
1981	10,187	20,310	30,517	2013	17,280	46,808	64,088
1982	10,201	20,716	30,938	2014	14,585	42,304	56,889
1983	9,363	22,494	31,883	2015	12,366	40,196	52,562
1984	9,766	26,427	35,072	2016	12,109	38,792	50,901
1985	12,151	30,413	41,382	2017	11,296	36,803	48,099
1986	12,737	33,726	46,495	2018	11,005	35,949	46,954
1987	14,810	36,465	51,275	2019	10,746	35,312	46,058
1988	16,722	41,639	58,361	2020	10,746	35,107	45,853
1989	16,845	43,489	60,334	2021	10,746	33,917	44,663
1990	20,861	44,947	65,808	2022	10,370	32,747	43,117
1991	23,060	46,819	69,879	2023	9,236	32,048	41,284
				2024	7,750	31,185	38,935
				2025	5,881	27,978	33,859
				2026	4,927	25,902	30,829
				2027	4,252	24,259	28,511
				2028	3,736	22,177	25,913
				2029	3,423	20,504	23,927
				2030	2,960	18,713	21,673

[a]Historical data for 1960-1990 are based on refs. 7 and 9 and for 1991 on ref. 10.
[b]Projected data for 1992-2030 are based on ref. 10.

Table C.9. Estimated sources and characteristics of commercial greater-than-Class-C LLW[a]

Waste source	Physical form	Primary isotopes of concern for disposal
Utilities		
Operations	Activated metals, instruments, filters, ion-exchange resins, sludges	^{59}Ni, ^{63}Ni, ^{94}Nb, and TRU isotopes
Decommissioning	Activated metals	^{59}Ni, ^{63}Ni, and ^{94}Nb
Fuel testing labs		
Burnup lab operation	Solidified liquids, metal cuttings, glassware, equipment, ion-exchange resins	^{90}Sr and TRU isotopes
Burnup lab decommissioning	Solidified liquids, metals, glassware, equipment	^{90}Sr and TRU isotopes
Sealed sources		
Manufacturer operations	Trash, metal, foils	^{14}C, ^{90}Sr, ^{137}Cs, ^{241}Am, and Pu isotopes
Manufacturer decommissioning	Trash, metal, foils	^{14}C, ^{90}Sr, ^{137}Cs, ^{241}Am, and Pu isotopes
Sources designated as waste	Sealed sources	^{137}Cs, ^{238}Pu, ^{239}Pu, and ^{241}Am
Other		
Carbon-14 users	Solidified process liquids	^{14}C
Test and research reactors	Activated metals	^{59}Ni, ^{94}Nb, and TRU isotopes
Other	Soil, trash	^{241}Am

[a]Gleaned from information given in refs. 11 and 12.

Table C.10. Projected number and volume of drums and classes of LLW incorporated in cement to be generated in the WVDP Low-Level Radwaste Treatment System[a,b,c,d]

End of calendar year	Number of drums			Total volume of drums (m^3)
	Class A[e]	Class B	Class C[f]	
1987	726	g	-	196
1988	-	g	2,024	546
1989	-	g	4,508	1,217
1990[h]	-	g	3,863	1,043
1991[i]	-	g	0	0
1992[j]	-	g	4,545	1,227
Total number	726	g	14,940	
Total volume, m^3	196	g	4,034	4,229

[a]The so-called square drums used are parallelopipeds of square cross section (~0.6 m x 0.6 m x 0.8 m) with a volume of 71 gal (0.27 m^3).

[b]The classes are in accordance with the Classes (A, B, or C) as set by requirements of the NRC in 10 CFR 61.55.

[c]Taken from ref. 13.

[d]Alkaline HLW liquid is processed (see Sect. 2) to yield a loaded ion-exchange material (zeolite), which is HLW, and an effluent, which is LLW. This effluent is solidified with cement.

[e]Generated in 1987 during equipment testing campaigns.

[f]Stored in a shielded drum cell.

[g]No Class B waste is expected to be generated with the effluent mentioned in footnote d.

[h]Processing of alkaline HLW liquid was completed in November 1990, leaving a 1,090-m^3 heel of liquid in the alkaline HLW waste (liquid plus sludge) storage tank.

[i]Processing of liquids from washing of HLW sludge is scheduled to begin in October 1991.

[j]The drums projected to be filled in 1992 will contain the liquids mentioned in footnotes h and i after treatment by ion exchange (see footnote d).

Table C.11. Composition of industrial and institutional waste by category[a]

Radionuclide	Composition,[b] %				
		Institutional			
	Industrial	Bioresearch	Medical	Nonbioresearch	Total
^{3}H	6.453E+01	5.286E+01	8.341E+00	8.824E+01	6.319E+01
^{14}C	3.815E-01	2.738E+01	6.107E+00	6.549E+00	4.454E+00
^{22}Na		1.652E-01			2.279E-02
^{32}P	6.340E+00	4.416E+00	7.367E+00		5.816E+00
^{36}Cl		3.239E-02			4.469E-03
^{35}S	5.519E+00	4.294E+00	8.735E-01		5.042E+00
^{45}Ca	8.671E-04	2.242E-02			3.791E-03
^{46}Sc			1.911E-02		2.571E-04
^{51}Cr	1.394E-01	2.775E-01	3.417E-01		1.550E-01
^{54}Mn	8.052E-02			3.987E-02	6.654E-02
^{55}Fe	2.336E-03	2.092E-03		6.577E-01	3.102E-02
^{57}Co	4.584E-03		6.575E-01		1.252E-02
^{58}Co	2.228E-03	2.318E-02			4.992E-03
^{59}Fe	9.859E-04			1.551E-02	1.473E-03
^{60}Co	3.366E+00			9.230E-01	2.748E+00
^{63}Ni	9.752E-03			5.037E-02	1.006E-02
^{65}Zn	1.196E-03	5.929E-02		1.398E-01	1.482E-02
^{67}Ga			7.758E-02		1.043E-03
^{75}Se	1.341E-02		2.419E-02		1.112E-02
^{85}Kr	4.061E-02				3.267E-02
^{90}Sr	3.310E-01				2.663E-01
^{90}Y	3.310E-01				2.663E-01
^{90}Mo			2.317E+00		3.114E-02
^{99m}Tc			7.023E-01		9.349E-03
^{109}Cd	8.790E-02				7.071E-02
^{111}In	6.475E-04		2.800E-02		8.969E-04
^{113}Sn			2.410E-02		3.240E-04
^{123}I	5.063E-04		2.190E-02		7.016E-04
^{125}I	1.703E+00	9.902E+00	7.064E+01		3.686E+00
^{131}I	1.465E-02	5.453E-01	5.652E-02		8.778E-02
^{133}Ba	2.674E-02				2.151E-02
^{133}Xe			3.828E-02		5.146E-04
^{134}Cs	2.605E-02				2.096E-02
^{137}Cs	6.008E+00	1.230E-02		1.250E+00	4.892E+00
^{137m}Ba	5.687E+00	1.164E-02		1.183E+00	4.625E+00
^{147}Pm	1.015E-01				8.167E-02
^{151}Sm	6.166E-03				4.960E-03
^{153}Gd			5.288E-03		7.107E-05
^{169}Yb	8.637E-02				6.948E-02
^{175}Hf	1.234E-02				9.924E-03
^{182}Ta	7.939E-01				6.387E-01
^{192}Ir	3.347E-01		1.995E+00		2.961E-01
^{201}Tl			2.585E-01		3.476E-03
^{210}Po	1.424E-01				1.146E-01
^{226}Ra			1.071E-01		1.439E-03
^{230}Th	7.489E-04				6.047E-03
^{232}Th	1.665E+00				1.341E+00
^{235}U	1.356E-02				1.091E-02
^{238}U	2.172E+00			9.484E-01	1.807E+00
^{241}Pu	1.806E-02				1.453E-02
Total	1.000E+02	1.000E+02	1.000E+02	1.000E+02	1.000E+02

[a]The volumetric composition of I/I is considered to be as follows: 70.3% industrial, 21.9% bioresearch, 2.3% medical, and 5.5% nonbioresearch. The radioactivity composition of I/I waste is considered to be 80.5% industrial, 13.8% bioresearch, 1.3% medical, and 4.4% nonbioresearch.

[b]The composition is presented as percent of total curies in each individual category of I/I waste and as percent of the total in all I/I waste combined. This information is adapted from ref. 2.

APPENDIX D. REFERENCE SITES AND FACILITIES

APPENDIX D. REFERENCE SITES AND FACILITIES

D.1 DISCUSSION

This appendix provides a listing of major DOE and commercial sites and facilities discussed in this report. Table D.1 lists major DOE sites and facilities. Major commercial radioactive waste disposal sites are given in Table D.2. For each site or facility listed in these tables, additional information is provided, including reference symbol or label, location, operations contractor, and, for DOE sites, the supervisory DOE field office.

Table D.1. Major DOE sites and facilities referred to in this report

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Ames Laboratory	AMES	Ames, IA	Iowa State University (515/294-2680)	Chicago (708/252-2001)
Argonne National Laboratory-East	ANL-E	Argonne, IL	University of Chicago (708/252-2000)	Chicago (708/252-2001)
Argonne National Laboratory-West[b]	ANL-W	Idaho Falls, ID	University of Chicago (208/533-7000)	Idaho (208/526-0111)
Battelle Columbus Laboratories Decommissioning Project	BCLDP	Columbus, OH	Battelle Memorial Institute (614/424-3989)	Chicago (708/252-2001)
Brookhaven National Laboratory	BNL	Upton, NY	Associated Universities, Inc. (516/282-2123)	Chicago (708/252-2001)
Colonie Interim Storage Site	CISS	Colonie, NY	Bechtel National, Inc. (615/220-2000)	Oak Ridge (615/576-5454)
Fermi National Accelerator Laboratory	FNAL	Batavia, IL	University Research Association (708/840-3000)	Chicago (708/252-2001)
Fernald Environmental Management Project	FEMP	Fernald, OH	Westinghouse Environmental Management Company of Ohio, Inc. (513/738-6200)	Fernald Field Office (513/738-6319)
Grand Junction Projects Office	GJPO	Grand Junction, CO	DOE Grand Junction Projects Office (303/248-6000)	Idaho (208/526-0111)
Hanford Site	HANF	Hanford, WA	Westinghouse Hanford Company, Inc. (509/376-7511)	Richland (509/376-7411)
Idaho National Engineering Laboratory	INEL	Idaho Falls, ID	EG&G Idaho, Inc. (208/526-0111)	Idaho (208/526-0111)
Inhalation Toxicology Research Institute	ITRI	Albuquerque, NM	Lovelace Biomedical and Environmental Research Institute, Inc. (505/845-1037)	Albuquerque (505/845-4154)
Kansas City Plant	KCP	Kansas City, MO	Allied-Signal Aerospace Company Kansas City Division (816/997-2000)	Albuquerque Kansas City Area Office (816/997-3348)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Lawrence Berkeley Laboratory	LBL	Berkeley, CA	University of California (510/486-4000)	San Francisco Lawrence Berkeley Laboratory Site Office (510/486-4363)
Lawrence Livermore National Laboratory	LLNL	Livermore, CA	University of California (510/422-1100)	San Francisco (510/273-6383)
Los Alamos National Laboratory	LANL	Los Alamos, NM	University of California (505/667-5061)	Albuquerque Los Alamos Area Office (505/667-5061)
Mound Plant	MOUND	Miamisburg, OH	EG&G Mound Applied Technologies (513/865-4020)	Albuquerque Dayton Area Office (513/865-3271)
Naval Reactors Program Facilities Bettis Atomic Power Laboratory	BAPL	West Mifflin, PA	Westinghouse Electric Corporation (412/476-5000)	DOE/HQ Office of Naval Reactors (NE-60) Pittsburgh Naval Reactors Area Office (412/476-5000)
Knolls Atomic Power Laboratory	KAPL	Schenectady, NY	General Electric Company (518/395-4000)	DOE/HQ Office of Naval Reactors (NE-60) Schenectady Naval Reactors Area Office (518/395-4000)
Naval Reactors Facility (INEL)	NRF	Idaho Falls, ID	Westinghouse Electric Corporation (208/526-0111)	DOE/HQ Office of Naval Reactors (NE-60) Pittsburgh Naval Reactors Area Office (412/476-5000)
Nevada Test Site	NTS	Mercury, NV	Reynolds Electrical & Engineering Company, Inc. (702/295-9060)	Nevada (702/295-1212)
Oak Ridge Institute for Science and Education	ORISE	Oak Ridge, TN	Oak Ridge Associated Universities (615/576-3000)	Oak Ridge (615/576-5454)
Oak Ridge K-25 Site	K-25	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge (615/576-5454)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Oak Ridge National Laboratory	ORNL	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge (615/576-5454)
Oak Ridge Y-12 Plant	Y-12	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge (615/576-5454)
Pacific Northwest Laboratory[c]	PNL	Richland, WA	Battelle Memorial Institute (509/375-2121)	Richland (509/376-7411)
Paducah Gaseous Diffusion Plant	PAD	Paducah, KY	Martin Marietta Energy Systems, Inc. (502/441-6000)	Oak Ridge Paducah Site Office (502/441-6800)
Pantex Plant	PANT	Amarillo, TX	Mason & Hanger – Silas Mason Company, Inc. (806/477-3000)	Albuquerque Amarillo Area Office (806/477-3000)
Pinellas Plant	Pinellas	Largo, FL	Martin Marietta Specialty Components, Inc. (813/541-8001)	Albuquerque Pinellas Area Office (813/541-8196)
Portsmouth Gaseous Diffusion Plant	PORTS	Portsmouth, OH	Martin Marietta Energy Systems, Inc. (614/897-2331)	Oak Ridge Portsmouth Area Office (614/897-2331)
Princeton Plasma Physics Laboratory	PPPL	Princeton, NJ	Princeton University (609/243-2000)	Chicago Princeton Area Office (609/243-3700)
Reactive Metals, Incorporated Extrusion Plant	RMI	Astabula, OH	RMI Titanium Company (216/992-7442)	Albuquerque Astabula Area Office (216/992-7442)
Rocky Flats Plant	RFP	Golden, CO	EG&G Rocky Flats, Inc. (303/966-7000)	Albuquerque Rocky Flats Office (303/966-7000)
Sandia National Laboratories Albuquerque	SNLA	Albuquerque, NM	AT&T Technologies, Inc. (505/844-5678)	Albuquerque (505/845-4154)
Livermore	SNLL	Livermore, CA	AT&T Technologies, Inc. (510/294-3000)	Albuquerque (505/845-4154)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor(s) for site operations (Phone number)[a]	DOE field office (Phone number)[a]
Santa Susana Field Laboratory (Energy Technology Engineering Center)	SSFL (ETEC)	Canoga Park, CA	Rockwell International Rocketdyne Division (818/586-5326)	San Francisco (510/273-6383)
Savannah River Site	SRS	Aiken, SC	Westinghouse Savannah River Company (803/725-6211)	Savannah River (803/725-6211)
Stanford Linear Accelerator Center	SLAC	Palo Alto, CA	Stanford University (415/926-3300)	San Francisco Stanford Site Office (415/926-3208)
Three Mile Island-Unit 2 Reactor	TMI-Unit 2	Middletown, PA	General Public Utilities (717/944-7621)	Idaho Three Mile Island Site Office (717/944-7621)
Waste Isolation Pilot Plant	WIPP	Carlsbad, NM	Westinghouse Electric Corporation WIPP Project Office (505/885-7500)	Albuquerque WIPP Project Office (505/887-8115)
Weldon Spring Site Remedial Action Project	WSSRAP	Weldon Spring, MO	Jacobs Engineering Group, Inc. MK-Ferguson Company (314/441-8978)	Oak Ridge Weldon Spring Site (314/441-8978)
West Valley Demonstration Project	WVDP	West Valley, NY	Westinghouse Electric Corporation West Valley Nuclear Services (716/942-3235)	Idaho West Valley Project Office (716/942-4313)

[a]Phone number for access to main organizations.
[b]Part of the Idaho National Engineering Laboratory.
[c]Part of the Hanford Site.

Table D.2. Major commercial radioactive waste disposal sites included in this report[a]

Site	Symbol/label	Location	Principal contractor for site operations (Phone number)[b]
Barnwell	BARN	Barnwell, SC	Chem-Nuclear Systems, Inc. (803/256-0450)
Beatty	BETY	Beatty, NV	US Ecology, Nuclear (702/553-2203)
Maxey Flats	MFKY	Hillsboro, KY	Westinghouse Electric Corporation Environmental Technology Division (606/784-6612)
Richland	RICH	Richland, WA	US Ecology, Nuclear (509/377-2411)
Sheffield	SHEF	Sheffield, IL	US Ecology, Nuclear (815/454-2077)
West Valley	WVNY	West Valley, NY	Westinghouse Electric Corporation West Valley Nuclear Fuel Services Company, Inc. (716/942-3235) New York State Energy Research and Development Authority (518/465-6251)

[a]Does not include uranium mill tailings sites. See Table 5.2.
[b]Phone number for access to main organizations.

GLOSSARY OF TERMS

Actinides: Elements with atomic numbers from 90 to 103 inclusive. (Note that actinium is not part of this group.)

Activation product: A radioactive material produced by bombardment with neutrons, protons, or other nuclear particles.

Agreement State: A state that has entered into an agreement with the Nuclear Regulatory Commission (as specified by the 1954 Atomic Energy Act) and has authority to regulate the disposal of low-level radioactive waste under such an agreement. This term is used in the Low-Level Radioactive Waste Policy Act (Public Law 99-240).

Alpha decay: Radioactive decay in which an alpha particle (^{4}He nucleus) is emitted.

Beta decay: Radioactive decay in which a negative electron (beta particle) is emitted.

Borosilicate glass: A type of glass containing at least 5% boric oxide. It is used in glassware that resists heat and is a leading candidate for use in high-level waste immobilization and disposal.

Branching ratio: The fraction of nuclei that disintegrates in a specific way. (It is usually expressed as a percentage.)

Burnup, specific: The total energy released per initial unit mass of reactor fuel as a result of fission. The unit commonly used for specific burnup is megawatt-days per metric ton of initial heavy metal, MWd/MTIHM.

By-product material: (1) Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material; (2) the tailings or waste products produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.

Calcine: A form of high-level waste produced from defense reactor fuel reprocessing waste (at the Idaho Chemical Processing Plant) by heating to a temperature below the melting point to bring about loss of moisture and oxidation to a chemically stable form.

Canister: A metal container used for the storage or disposal of heat-producing solid radioactive waste.

Capacity factor, plant: The ratio of the electrical energy actually supplied by a power plant in a given time interval to the electrical energy that could have been produced at continuous full-power operation during the same time period.

Capsules: Encapsulated strontium and cesium high-level wastes produced from defense reactor fuel reprocessing at the Hanford site.

Cladding: A corrosion-resistant tube, commonly made of zirconium alloy or stainless steel, surrounding the reactor fuel pellets which provides protection from a chemically reactive environment and containment of fission products.

Code of Federal Regulations: A documentation of the general rules by the executive departments of the federal government. The code is divided into 50 titles that represent broad areas subject to federal regulation. Each title is divided into chapters that usually bear the name of the issuing agency. Each chapter is further subdivided into parts covering specific regulatory areas.

Control rod: A movable part of a reactor used to regulate the degree of fuel fissioning in the core.

Conversion, fuel: Chemical treatment of yellowcake (U_3O_8) to uranium hexafluoride (UF_6) in preparation for enrichment.

Core, nuclear reactor: That part of the reactor which contains the nuclear fuel and in which most or all of the nuclear fissions occur.

Daughter product(s): The nuclide(s) formed by the radioactive disintegration of a first radionuclide (parent).

Decay, radioactive: The transition of a nucleus from one energy state to a lower one, usually involving the emission of a photon, electron, or neutron.

Decay chain, radioactive: A series of nuclides in which each member transforms into the next through radioactive decay until a stable nuclide has been formed.

Decommissioning: Preparations taken for retirement of a nuclear facility from active service, accompanied by the execution of a program to reduce or stabilize radioactive contamination.

Decommissioning wastes: Wastes (generally low-level) collected or resulting from facility decommissioning activities.

Decontamination: Those activities employed to reduce radiation levels or to remove radioactive contamination in or on structures, equipment, and materials.

Deep bed plant: A BWR facility using a demineralizer vessel for water purification which contains an ion-exchange resin that is 3 or more feet deep.

Disintegration energy (Q): The amount of energy released in a particular nuclear disintegration. This is usually expressed in MeV per disintegration.

DOE waste: Radioactive waste produced from activities supported by the Department of Energy and/or U.S. government defense programs.

Double-shell tank wastes: High-level wastes, generated from defense reactor fuel reprocessing at Hanford, which are stored in double-shelled tanks. These wastes consist of a mixture of liquid and suspended solids referred to as slurry. See also "single-shell tank wastes."

Electron capture: Radioactive decay in which an orbital electron is captured by the nucleus.

Enrichment, fuel: A nuclear fuel cycle process in which the concentration of fissionable uranium (i.e., ^{235}U) is increased above its natural level of 0.71%. (The method currently utilized in the United States is gaseous diffusion.)

Environmental Impact Statement: A report that documents the information required to evaluate the environmental impact of a project. Such a report informs decision-makers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the environment.

Environmental restoration project: A group of activities initiated to access a DOE facility or radioactive waste site that may require restoration to acceptable radiation levels.

Equilibrium cycle: An assumed nuclear fuel cycle condition in which the feed and waste materials of a facility have constant compositions. In a reactor this condition typically results after the third or fourth fuel loading schedule.

Fabrication, fuel: Conversion of enriched UF_6 into pellets of ceramic uranium dioxide (UO_2). These pellets are then sealed into corrosion-resistant tubes of zirconium alloy or stainless steel. The loaded tubes, called fuel elements or rods, are then mounted into special assemblies for loading into the reactor core.

Fertile nuclide: A nuclide capable of being transformed into a fissile nuclide by neutron capture at specific neutron energies.

Filter/demineralizer plant: A facility that combines filtration and ion-exchange processing using nonregenerable powered resins.

Fissile nuclide: A nuclide capable of undergoing nuclear fission with neutrons.

Fission, nuclear: The division of a heavy atomic nucleus into two (or, rarely, more) parts with similar masses, usually accompanied by the emission of neutrons and gamma radiation.

Fission products: Nuclides produced either by fission or by the subsequent decay of the nuclides thus formed.

Fission, spontaneous: Nuclear fission that occurs without the addition of particles or energy to the nucleus.

Formerly utilized site: A site contaminated with radioactive wastes which was previously used for supporting nuclear activities of the DOE's predecessor agencies, the Manhattan Engineer District (Manhattan Project) and the Atomic Energy Commission.

Fuel assembly: A grouping of nuclear fuel rods that remains integral during the charging and discharging of a reactor core.

Fuel cycle, nuclear: The complete series of steps involved in supplying fuel for nuclear reactors. It includes mining, refining, enrichment, fabrication of fuel elements, use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication of new fuel elements, and management of radioactive waste.

Generation (electricity): The process of producing electric energy from other forms of energy; also, the amount of electric energy produced, commonly expressed in kilowatt-hours (kWh) or megawatt-years [MW(e)-years].

Generation (gross): The total amount of electric energy produced by the generating units in a generating station or stations, measured at the generator terminals.

Generation (net): Gross generation less the electric energy consumed at the generating station for station use.

Glass frit: A fusible ceramic mixture used to make glass for use in the immobilization and disposal of high-level wastes.

Greater-than-Class-C low-level waste: Waste from commercial sources containing radionuclide concentrations that exceed Nuclear Regulatory Commission limits for Class C low-level radioactive waste as defined in 10 CFR Part 61.55.

Grout: A mortar or cement mixture used to immobilize radioactive wastes.

Half-life, radioactive: For a single radioactive decay process, the time required for the activity to decrease to half its initial value by that process.

Hazardous waste: Nonradioactive waste containing concentrations of either toxic, corrosive, flammable, or reactive chemicals above maximum permissible levels as defined by the Environmental Protection Agency in 40 CFR Part 261 or polychlorinated biphenyls (PCBs) above maximum permissible levels as defined by the EPA in 40 CFR Parts 702–799.

High-level waste: As defined by the Nuclear Waste Policy Act, high-level waste is (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including the liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (2) other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.

Hydrofracture: A process formerly used for permanent disposal of low-level (approximately 0.25 Ci/L) liquid waste at the Oak Ridge National Laboratory. The process involved mixing the waste with a blend of cement and other additives with the resulting grout being injected into shale at a depth of 200 to 300 m. The injected grout hardened into thin, horizontal sheets several hundred meters wide.

Industrial waste: Commercial low-level waste resulting from non-nuclear fuel cycle sources. These include the commercial producers of radiochemicals and radiopharmaceuticals, luminous dial manufacturers, and instruments that incorporate sealed source components (e.g., smoke detectors).

Institutional waste: Commercial low-level waste resulting from bioresearch, medical, and certain nonbioresearch sources. Bioresearch wastes include wastes from animal studies at universities. Medical wastes include those generated from diagnostic and therapeutic procedures on humans at hospitals. Nonbioresearch wastes include research reactor wastes; small-volume, sealed radiation sources; and accelerator targets.

Leaching: The process of removal or separation of soluble components from a solid by percolating water or other liquids through the solid.

Low-level waste: As specified in the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240), radioactive waste not classified as high-level waste, spent nuclear fuel, or by-product material specified as uranium or thorium tailings and waste.

Mill tailings, uranium: Earthen residues that remain after the extraction of uranium from ores. Tailings may also contain other minerals or metals not extracted in the process.

Mixed low-level waste: Waste that satisfies the definition of low-level radioactive waste (LLW) in the Low-Level Radioactive Waste Policy Amendments Act of 1985 and contains hazardous waste that has at least one of the following characteristics: (1) is listed as a hazardous waste in Subpart D of 40 CFR Part 261, (2) exhibits any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261, or (3) contains PCB-containing wastes subject to regulation under the Toxic Substances Control Act and 40 CFR Parts 702–799.

Mixed waste: Waste that includes concentrations of both radionuclides and hazardous chemicals.

Moderator: A material used to reduce neutron energy (for fissioning if in a reactor) by elastic scattering.

MRS facility: A proposed facility for the monitored retrievable storage of spent fuel from commercial power plants. Such a facility would permit continuous monitoring, management, and maintenance of these wastes and provide for their ready retrieval for further processing or disposal.

Neutron activation: The process of irradiating a material with neutrons so that the material itself is transformed into a radioactive nuclide.

Nonfuel components: Nuclear reactor core parts and hardware, excluding the nuclear fuel itself. Such components include shrouds, control rods, fuel channels, in-core chambers, support tubes, and dummy fuel rods.

Parent: A radionuclide that upon decay yields a specified nuclide (the daughter) either directly or as a later member of a radioactive decay series.

Pressure vessel, reactor: A strong-walled container housing the core of most types of power reactors. It usually also contains other core components such as the moderator and control rods.

PUREX process: A solvent extraction process that may be employed in the reprocessing of uranium/plutonium-based nuclear fuels.

Radioactivity: The number of spontaneous nuclear disintegrations occurring in a given quantity of material during a suitably small period of time. A unit of activity commonly used is the curie (Ci), which is 3.7×10^{10} disintegrations per second.

Reactor, boiling-water: A light-water reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam is used directly to drive a turbine.

Reactor, breeder: A reactor that produces more fissionable fuel than it consumes. The new fissionable material is created by a process (breeding) in which fission neutrons are captured in fertile materials.

Reactor, fast flux: A reactor in which fission is induced predominantly by fast neutrons.

Reactor, high-temperature, gas-cooled: A nuclear reactor that uses an inert gas (helium) as the primary coolant and a graphite moderator.

Reactor, light-water: A nuclear reactor that uses light water (H_2O) as the primary coolant and moderator, with slightly enriched uranium as the fuel. There are two types of commercial light-water reactors: boiling-water and pressurized-water.

Reactor, naval propulsion: A reactor used to power a vessel or submarine of the U.S. Navy.

Reactor, pressurized-water: A light-water reactor in which heat is transferred from the core to a heat exchanger via water kept under high pressure, so that high temperatures can be maintained in the primary system without boiling the water. Steam is generated in a secondary circuit.

Reactor, production: A reactor whose primary purpose is to produce fissile or other materials or to perform irradiations on an industrial scale. Unless otherwise specified, the term usually refers to either a tritium- or plutonium-production facility used to produce materials for nuclear weapons.

Reactor, research: A reactor whose nuclear radiations are used primarily as a tool for basic or applied research. Typically, it has a thermal power of 10 MW(t) or less and may include facilities for testing reactor materials.

Reactor, test: A reactor associated with an engineering-scale test program conducted for the purpose of developing basic design information or demonstrating safety characteristics of nuclear reactor systems.

Reinserted fuel: Irradiated reactor fuel that is discharged in one cycle and inserted in the same reactor during a subsequent refueling. In a few cases, fuel discharged from one reactor has been used to fuel a different reactor.

Repository, geologic: A facility that has an excavated subsurface system for the permanent disposal of spent fuel and high-level waste.

Reprocessing, fuel: The chemical/mechanical processing of irradiated nuclear reactor fuel to remove fission products and recover fissile and fertile material.

Salt cake: A salt form of high-level waste stored in tanks which is produced from neutralizing acidic liquid waste from defense reactor fuel reprocessing with an alkaline agent (caustic soda).

Saltstone: A low-level waste by-product from the solidification of high-level waste at the Savannah River Site. Saltstone is retained in trenches at Savannah River.

Sea-bed disposal: Placement of waste packages in deep ocean sediments.

Sea dumping (disposal): The practice of periodically dumping shiploads of drummed, solidified waste at specified locations in the ocean.

Separative work unit: The standard measure of enrichment services. The separative work unit (SWU) is expressed as a unit of mass. For example, one kilogram of separative work is expressed as 1 kg SWU.

Single-shell tank wastes: High-level wastes, generated from defense reactor fuel reprocessing at Hanford, which are stored in single-shelled tanks. These tanks contain inventories of liquid, sludge, and salt cake. See also "double-shell tank wastes."

Slurry, high-level waste: A watery mixture of highly radioactive, insoluble matter.

Solvent extraction: The separation of materials of different chemical types and solubilities by selective solvent action; used to recover and separate uranium and plutonium in reprocessing spent nuclear fuel.

Source term (IDB Program usage): A set of qualitative and quantitative features used to describe the origin and concentration of radioactive waste. The qualitative features include a flowchart of waste streams generated by a facility or an activity. Quantitative features include (1) the number of curies of radioactivity expressed either per unit of facility production or per unit of waste volume or mass; and (2) a listing of the relative concentrations of component radioisotopes per curie of waste activity.

Special nuclear material: Plutonium or uranium enriched to a higher than natural assay.

Spent fuel: Nuclear fuel that has been permanently discharged from a reactor after it has been irradiated. Typically, spent fuel is measured in terms of either the number of discharged fuel assemblies or the quantity of discharged fuel mass. The latter is measured either in metric tons of heavy metal (i.e., only the heavy metal content of the spent fuel is considered) or in metric tons of initial heavy metal (essentially, the initial mass of the fuel before irradiation). The difference between these two quantities is the weight of the fission products.

Thermal power: A measure of the rate of heat energy emission that results from the radioactive decay of a material. A unit of thermal power commonly used is the watt (W).

THOREX process: A solvent extraction process developed for the reprocessing of thorium-based nuclear fuels.

Transuranic waste: As defined and used by the Department of Energy (DOE Order 5820.2A), radioactive waste that, at the time of assay, contains more than 100 nCi/g of alpha-emitting isotopes with atomic numbers greater than 92 and half-lives greater than 20 years.

Transuranic waste acceptance criteria: A set of conditions established for permitting transuranic wastes to be disposed at the Waste Isolation Pilot Plant.

Transuranic waste certification: The process for verifying that a suspect radioactive waste is transuranic.

Transuranic waste, contact-handled: Transuranic waste with a surface dose rate of less than 200 mrem/h and minimal heat generation to permit handling by contact methods.

Transuranic waste nondestructive assay/nondestructive examination: Nondestructive test procedures performed on suspect transuranic wastes to determine their transuranic isotope concentration. From these tests such wastes can be properly classified (certified) as transuranic or low-level.

Transuranic waste, remote-handled: Transuranic waste with a surface dose rate of greater than 200 mrem/h and/or heat generation to require remote handling and/or shielding.

Vitrification: The conversion of high-level waste materials into a glassy or noncrystalline solid for subsequent disposal.

Waste Isolation Pilot Plant: A research and development facility, located near Carlsbad, New Mexico, to be used for demonstrating the safe disposal of wastes from DOE activities.

Yellowcake: A uranium oxide concentrate that results from milling (concentrating) uranium ore. It typically contains 80 to 90% U_3O_8.

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