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Integrated Data Base for 1990: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics

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PREFACE

The information in this report summarizes the U.S. Department of Energy (DOE) data base for inventories, projections, and characteristics of domestic spent nuclear fuel and radioactive waste. This report is updated annually to keep abreast of continual changes. Baseline information is provided for planning purposes and to support program decisions. Although the primary purpose of this document is to provide background information for program planning within the DOE community, it has also been found useful by state and local governments, the academic community, and a number of private citizens. To sustain the objectives of this program in providing accurate and complete data in this field of operation, comments and suggestions to improve the quality and coverage are encouraged. Such comments and any general inquiries should be directed to:

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An important part of the Integrated Data Base Program is the Steering Committee, whose members provide both generic guidance and technical input. The membership of this Committee, shown on the following page, represents all of the major DOE sites and programs for spent fuel and radioactive waste management. Each support committee member is backed up by a technical liaison as needed and by a DOE liaison as appropriate. The participation and assistance of these individuals are acknowledged with appreciation.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AEA	Atomic Energy Act (of 1954)
AEC	Atomic Energy Commission
AMI	Academic/Medical/Industrial wastes
ANL-E	Argonne National Laboratory-East; Argonne, Illinois
ANL-W	Argonne National Laboratory-West; INEL, Idaho
ATL 1	Atlantic Site 1 (38'31'N, 72'06'W)
ATL 2	Atlantic Site 2 (37'50'N, 70'35'W)
BARN	Barnwell, South Carolina (commercial waste site)
BETTIS	Bettis Atomic Power Laboratory; West Mifflin, Pennsylvania
BETY	Beatty, Nevada (commercial waste site)
BNI	Bechtel National, Inc.; Oak Ridge, Tennessee
BNL	Brookhaven National Laboratory; Brookhaven, New York
BWR	Boiling-water reactor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (of 1980)
CFC	Chlorinated fluorocarbon
CH	Contact-handled (TRU waste)
CY	Calendar year
DOD	Department of Defense
DOE	Department of Energy
DOE/AL	DOE/Albuquerque Operations; Albuquerque, New Mexico
DOE/CH	DOE/Chicago Operations; Argonne, Illinois
DOE/DP	DOE/Office of Defense Programs (Headquarters); Germantown, Maryland (now DOE/EM)
DOE/EIA	DOE/Energy Information Administration; Washington, D.C.
DOE/EM	DOE/Office of Environmental Restoration and Waste Management (Headquarters); Germantown, Maryland
DOE/HQ	DOE Headquarters; Washington, D.C. and Germantown, Maryland
DOE/ID	DOE/Idaho Operations; Idaho Falls, Idaho
DOE/NV	DOE/Nevada Operations; Las Vegas, Nevada
DOE/OR	DOE/Oak Ridge Operations; Oak Ridge, Tennessee
DOE/OSTI	DOE/Office of Scientific and Technical Information; Oak Ridge, Tennessee
DOE/RL	DOE/Richland Operations; Richland, Washington
DOE/RW	DOE/Office of Civilian Radioactive Waste Management (Headquarters); Washington, D.C.
DOE/SAN	DOE/San Francisco Operations; Oakland, California
DOE/SR	DOE/Savannah River Operations; Aiken, South Carolina
DOE/WIPP	DOE/WIPP Project Office; Carlsbad, New Mexico
DOE/WVP	DOE/West Valley Project Office; West Valley, New York
DOT	Department of Transportation
DWMP	Defense Waste Management Plan
DWPF	Defense Waste Processing Facility
D&D	Decontamination and decommissioning
EA	Environmental assessment
EG&G/ID	EG&G Idaho, Inc.; Idaho Falls, Idaho
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ER	Environmental Restoration (Program)
FFTF	Fast Flux Test Facility; Hanford, Washington
FMPC	Feed Materials Production Center; Fernald, Ohio

FIS	Farallon Islands (Pacific Ocean off Central California)
FNAL	Fermi National Accelerator Laboratory; Batavia, Illinois
FSVR	Fort St. Vrain Reactor; Platteville, Colorado
FUSRAP	Formerly Utilized Sites Remedial Action Program
FY	Fiscal year
GJRAP	Grand Junction Remedial Action Project
GPU	General Public Utilities Corporation; Parsippany, New Jersey
GTCC	Greater-than-Class-C (low-level waste)
HANF	Hanford Site; Richland, Washington
HAZWRAP	Hazardous Waste Remedial Actions Program
HEN	Cape Henry (Atlantic Ocean off Virginia)
HLW	High-level waste
HTGR	High-temperature, gas-cooled reactor
HWVP	Hanford Waste Vitrification Plant; Hanford Site
ICPP	Idaho Chemical Processing Plant; INEL, Idaho
IDB	Integrated Data Base (Program)
I/I	Industrial and institutional (waste)
INEL	Idaho National Engineering Laboratory; Idaho Falls, Idaho
ITRI	Inhalation Toxicology Research Institute, Kirtland Air Force Base; Albuquerque, New Mexico
JIO	Joint Integration Office; Albuquerque, New Mexico
KAPL	Knolls Atomic Power Laboratory; Schenectady, New York
LANL	Los Alamos National Laboratory; Los Alamos, New Mexico
LGR	Light-water cooled, graphite-moderated reactor
LLNL	Lawrence Livermore National Laboratory; Livermore, California
LLRWPA	Low-Level Radioactive Waste Policy Act (of 1980)
LLRWPAA	Low-Level Radioactive Waste Policy Amendments Act (of 1985)
LLW	Low-level waste
LLWMP	Low-Level Waste Management Program
LSA	Low specific activity
LWR	Light-water reactor
LWBR	Light-water breeder reactor
MASS	Massachusetts Bay
MED	Manhattan Engineer District (Manhattan Project)
MFKY	Maxey Flats, Kentucky (commercial waste site)
MFRP	Midwest Fuel Recovery Plant; Morris, Illinois (commercial spent fuel storage site)
MIMS	Manifest Information Management System
MMES	Martin Marietta Energy Systems, Inc.
MOUND	Mound Plant; Miamisburg, Ohio
MRM	Miscellaneous radioactive material
MRS	Monitored retrievable storage
MTIHM	Metric tons initial heavy metal
MTU	Metric tons uranium
NA	Not applicable
NARM	Nuclear accelerator-generated radioactive material
NEPA	National Environmental Policy Act (of 1969)
NFS	Nuclear Fuel Services; West Valley, New York (now called the West Valley Demonstration Project)
NNFD	Naval Nuclear Fuel Division (Research Laboratory); Lynchburg, Virginia
NORM	Naturally occurring radioactive material
NRC	Nuclear Regulatory Commission
NRF	Naval Reactor Facility; INEL, Idaho
NTIS	National Technical Information Service; Springfield, Virginia
NTS	Nevada Test Site; Mercury, Nevada
NUMARC	Nuclear Management and Resources Council; Washington, D.C.
NUS	NUS Corporation; Gaithersburg, Maryland
NWPA	Nuclear Waste Policy Act (of 1982)
NWPAA	Nuclear Waste Policy Amendments Act (of 1987)
NYSERDA	New York State Energy Research and Development Authority; Albany, New York
OR	Oak Ridge complex: ORNL, ORGDP, Y-12; Oak Ridge, Tennessee

ORAU	Oak Ridge Associated Universities; Oak Ridge, Tennessee
ORGDP	Oak Ridge Gaseous Diffusion Plant; Oak Ridge, Tennessee
ORIGEN2	Oak Ridge Isotope Generation and Depletion Code (Version 2)
ORNL	Oak Ridge National Laboratory; Oak Ridge, Tennessee
OTA	U.S. Congress, Office of Technology Assessment; Washington, D.C.
PAD	Paducah Gaseous Diffusion Plant; Paducah, Kentucky
PANT	Pantex Plant; Amarillo, Texas
PCB	Polychlorinated biphenyl
PNL	Pacific Northwest Laboratory (Battelle); Richland, Washington
PNRO	DOE Pittsburgh Naval Reactor Office; West Mifflin, Pennsylvania
PORTS	Portsmouth Gaseous Diffusion Plant; Portsmouth, Ohio
PPPL	Princeton Plasma Physics Laboratory; Princeton, New Jersey
PWR	Pressurized-water reactor
RCRA	Resource Conservation and Recovery Act (of 1976)
REECO	Reynolds Electrical and Engineering Co., Inc.; Mercury, Nevada
RFP	Rocky Flats Plant; Golden, Colorado
RH	Remote-handled (TRU waste)
RI	Rockwell International Corporation; Pittsburgh, Pennsylvania
RICH	Richland, Washington (commercial waste site)
SCB	Santa Cruz Basin (Pacific Ocean off California)
SDG	San Diego (Pacific Ocean off San Diego)
SEG	Scientific Ecology Group, Inc.; Oak Ridge, Tennessee
SF	Spent fuel
SFMP	Surplus Facilities Management Program
SHEF	Sheffield, Illinois (commercial waste site)
SIS	Special Isotope Separation Project (Idaho National Engineering Laboratory)
SNLA	Sandia National Laboratory; Albuquerque, New Mexico
SNLL	Sandia National Laboratory; Livermore, California
SNM	Special nuclear material
SRS	Savannah River Site; Aiken, South Carolina
SWIMS	Solid Waste Information Management System
SWU	Separative work unit
TBD	To be determined
TRIGA	Training Reactor, Isotopes, General Atomic
TRU	Transuranic (waste)
TSCA	Toxic Substances Control Act (of 1976)
TVA	Tennessee Valley Authority; Knoxville, Tennessee
UMTRAP	Uranium Mill Tailings Remedial Action Program
WEC	Westinghouse Electric Corporation; Pittsburgh, Pennsylvania
WHC	Westinghouse Hanford Company; Richland, Washington
WHPP	(TRU) Waste Handling and Packaging Plant; Oak Ridge National Laboratory
WIPP	Waste Isolation Pilot Plant; Carlsbad, New Mexico
WMTC	Waste Management Technology Center (at ORNL)
WSPG	Weldon Spring Quarry and Raffinate Pits; Weldon Spring, Missouri
WVDP	West Valley Demonstration Project; New York (DOE site since 1982)
WVNS	West Valley Nuclear Services Company, Inc.; West Valley, New York
WVNY	West Valley, New York (commercial waste site from 1963–1981)
W/WIPP	Westinghouse/WIPP Project; Carlsbad, New Mexico
Y-12	Y-12 Plant; Oak Ridge, Tennessee

INTEGRATED DATA BASE FOR 1990: U.S. SPENT FUEL AND RADIOACTIVE WASTE INVENTORIES, PROJECTIONS, AND CHARACTERISTICS

ABSTRACT

The Integrated Data Base (IDB) Program has compiled current data on inventories and characteristics of commercial spent fuel and both commercial and U.S. government-owned radioactive wastes through December 31, 1989. These data are based on the most reliable information available from government sources, the open literature, technical reports, and direct contacts. The current projections of future waste and spent fuel to be generated through the year 2020 and characteristics of these materials are also presented. The information forecasted is consistent with the latest U.S. Department of Energy/Energy Information Administration (DOE/EIA) projections of U.S. commercial nuclear power growth and the expected DOE-related and private industrial and institutional (I/I) activities.

The radioactive materials considered, on a chapter-by-chapter basis, are spent fuel, high-level waste, transuranic waste, low-level waste, commercial uranium mill tailings, environmental restoration wastes, commercial reactor and fuel cycle facility decommissioning wastes, and mixed (hazardous and radioactive) low-level waste. For most of these categories, current and projected inventories are given through the year 2020, and the radioactivity and thermal power are calculated based on reported or estimated isotopic compositions. In addition, characteristics and current inventories are reported for miscellaneous radioactive materials that may require geologic disposal.

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0. OVERVIEW

0.1 INTRODUCTION

This report is an update of the previous document on radioactive waste inventories and projections that was prepared for use in the planning and analysis of waste management functions.[1] Historical waste inventories compiled as of December 31, 1989, are reported. This document contains information that has been assembled as a part of the Integrated Data Base (IDB) Program at Oak Ridge National Laboratory (ORNL), which has the lead responsibility for establishing and maintaining files of pertinent data on current and projected inventories and characteristics of permanently discharged domestic spent nuclear fuel and radioactive wastes. The data presented in this report were obtained through the cooperation and assistance of the offices and programs that were established by the U.S. Department of Energy (DOE) to oversee the management of the various radioactive wastes and spent fuels. In addition, the recent literature was reviewed to aid in selecting the data and to help establish a basis for many of the calculated radioactivity levels and heat generation rates that are included. In this report, spent fuel and radioactive wastes are characterized from the standpoint of their volumes (or masses) and their nuclear, physical, and chemical properties. The data reported are selected from more extensive information that is available upon request.

This annual inventory report contains summarized or executive-level data found to be useful for programmatic planning purposes within the DOE community. It does not contain detailed package-by-package waste information that might be required for design or cost analyses. Such information is available from the appropriate waste site or program office. These sources can be located by consulting the references within this document or by contacting the IDB Program. Because of the summary-level nature of this report, detailed discussions of specific analyses are avoided. Although some analyses for determining source terms and projections are needed, those involving transportation requirements, costs, shielding, packaging efficiencies, and health and environmental effects are purposely avoided. The data in this report should provide a common basis for management-level program planning and analysis by DOE contractors and field offices. It is expected that individuals involved with various DOE waste program analyses will use data that are in agreement with those maintained by the IDB Program.

Information for this report was provided by a variety of sources. Most waste data are received from DOE contractors through DOE field offices. DOE Headquarters assigns to selected organizations major responsibilities for particular topics involving spent fuel and radioactive waste management. Table 0.1 lists the technical areas and major sources of raw data input required by the IDB Program for this annual report. Further detailed information is generally available from data bases maintained at the specific DOE and commercial sites. A list of reference sites and facilities referred to in this report is provided in Appendix D.

Radioactive waste originates from five major sources: (1) the commercial nuclear fuel cycle; (2) DOE-related activities; (3) institutions such as hospitals, universities, and research foundations; (4) industrial uses of radioisotopes; and (5) mining and milling of uranium ore. The waste is broadly characterized as high-level waste (HLW), transuranic (TRU) waste, low-level waste (LLW), and uranium mill tailings.

In addition, future inventories of spent reactor fuel may require either storage expansion or construction of additional facilities for interim storage, pending the availability of interim storage, monitored retrievable storage (MRS), or permanent disposal facilities. Large quantities of radioactive waste will also result from future activities such as DOE environmental restoration activities and the decontamination and decommissioning (D&D) of commercial nuclear facilities.

0.2 CHARACTERIZATION OF WASTE FORMS

The major characteristics of radioactive materials and wastes are described below.

- Spent fuel consists of irradiated fuel discharged from a nuclear reactor. Unless otherwise identified, all spent fuels discussed in this report are assumed to be permanently discharged and eligible for repository disposal. Three categories of permanently discharged spent fuel are considered: (1) fuel from commercial light-water reactors (LWRs); (2) fuel from one-of-a-kind commercial reactors [e.g. the Fort St. Vrain high-temperature, gas-cooled reactor (HTGR)]; and (3) special fuels that are associated with government-sponsored research and demonstration programs, universities, and private industries. This report does not consider government production reactor spent fuels, which are reprocessed in the manufacture of nuclear weapons for national defense.

  Currently, most LWR spent fuel assemblies are stored in pools at the reactor sites. The remainder are in storage at the West Valley Demonstration Project (WVDP) site at West Valley, New York, and at the Midwest Fuel Recovery Plant (MFRP) at Morris, Illinois. The WVDP facility is currently being decommissioned. All utility-owned spent fuel assemblies previously stored there have been returned to the utilities, and the fuel remaining is DOE-owned material.

  Spent fuels from one-of-a-kind reactors are currently stored at Hanford and the Idaho National Engineering Laboratory (INEL). Spent fuel from the Fort St. Vrain HTGR is stored at the Idaho Chemical Processing Plant (ICPP) at INEL. Other types of special spent fuel are stored at the Savannah River Site (SRS) and INEL. These fuels are government owned and are not scheduled for reprocessing in support of DOE activities.

- For this report, HLW means the highly radioactive material resulting from the reprocessing of spent nuclear fuel. This includes mainly the liquid wastes remaining from the recovery of uranium and plutonium in a fuel reprocessing plant. This HLW may also be in the form of sludge, calcine, or other products into which such liquid wastes are converted to facilitate their handling and storage. Such waste contains fission products that result in the release of considerable decay energy.[2,3] For this reason, heavy shielding is required to control penetrating radiation and to dissipate decay heat from HLW.

- Transuranic wastes refer to radioactive wastes that contain more than 100 nCi/g of alpha-emitting isotopes with atomic numbers greater than 92 and half-lives greater than 20 years.[3,4] Such wastes result primarily from fuel reprocessing and from the fabrication of plutonium weapons and

plutonium-bearing reactor fuel. Generally, little or no shielding is required ("contact-handled" TRU waste), but energetic gamma and neutron emissions from certain TRU nuclides and fission-product contaminants may require shielding or remote handling ("remote-handled" TRU waste).

- Low-level waste is radioactive waste not classified as spent fuel, HLW, TRU waste, or by-product material, such as uranium mill tailings. The radiation level from this waste may sometimes be high enough to require shielding for handling and transport. In ref. 5, the U.S. Nuclear Regulatory Commission (NRC) has defined four disposal categories of LLW that require differing degrees of confinement and/or monitoring: classes A, B, C, and greater-than-Class-C (GTCC). The NRC also excludes naturally occurring and accelerator-produced radioactive material from the LLW category. This report documents only those inventories of solid LLW going to burial. It does not include any liquid or gas waste in storage, nor inventories of soils contaminated with LLW.

- Commercial uranium mill tailings are the earthen residues that remain after the extraction of uranium from ores. Tailings are generated in very large volumes and contain low concentrations of naturally occurring radioactive materials. Because they provide a potential health hazard, the isotopes of major concern are ^{226}Ra and its daughter, ^{222}Rn.

- Miscellaneous radioactive materials (MRM) that could possibly require geologic disposal are presently stored at some DOE and commercial sites. These materials include spent fuel elements for which no reprocessing is planned and "TRU"-type wastes from commercial sources.

- Mixed LLW includes concentrations of both low-level radioactive materials and hazardous chemicals. Characteristics of the latter are defined by the Resource Conservation and Recovery Act (RCRA).[6] Typically, mixed LLW from activities supporting DOE programs includes a broad spectrum of contaminated materials, such as air purifiers, cleaning solutions, engine oils, epoxies and resins, gravel, laser dyes, paint residues, soils, asphalt, roofing and wall materials, water treatment chemicals, and decommissioned weapons manufacturing equipment.[7] This report documents inventories and generation rates of various types of mixed wastes stored at DOE sites. A data base for mixed wastes from activities at government installations is being compiled by the Hazardous Waste Remedial Actions Program (HAZWRAP) in support of the DOE Office of Environmental Restoration and Waste Management.

It should be emphasized that all of the types of radioactive materials and wastes discussed in this report can exist either as material generated, treated, stored, or disposed. The distinctions among these various waste conditions or "states" are as follows:

- Generated waste. A material stream recently discharged from a facility production process or operation that can be regarded as a waste because it has no economic value. In this report, quantities of generated waste are measured in units of volume (m^3) or mass (kg) produced during a calendar year.

- Treated waste. A waste stream that, following generation, has been altered chemically or physically to reduce its toxicity or prepare it for storage or disposal on- or off-site. Waste treatment can include volume reduction activities, such as incineration or compaction, which may be performed on a waste prior to either storage or disposal or both (discussed below). Inventories and projections of waste materials undergoing treatment at various sites are not reported in this document.

- Stored waste. A waste that, following generation (and usually some treatment), is being (temporarily) retained and monitored in a retrievable manner pending disposal. In this report, inventories and projections of stored radioactive materials or wastes are reported in volume (m^3) or mass (kg) units or both.

- Disposed waste. A waste that has been put in final emplacement to ensure its isolation from the biosphere, with no intention of retrieval. Deliberate action is required to regain access to the waste. Disposed waste includes materials placed in a geologic repository, buried in shallow-land pits, dumped at sea, or discarded by hydrofracture injection.

Throughout this report, the reader is urged to note the distinctions between these waste conditions. Such conditions have a great impact on the regulatory status of the waste materials considered in this report.

0.3 METHODS AND ASSUMPTIONS USED IN REPORT PREPARATION

This report consolidates a large amount of information from many sources. Some of these data are historical in nature, some are current, and some are calculated; some have been estimated, and some have been measured. Over the years, waste regulations have been revised, waste category definitions have changed, measurement instruments and calibration methods have

been improved, and record-keeping has been upgraded at all waste generating and receiving sites. In preparing this report, a major effort has been made to integrate waste data from many sources, striving for a consistent and technically rational approach for the entire scope of coverage. Our primary sources of data are referenced, and, for calculated values (e.g., radioactive decay and thermal power), the bases for the calculations are identified. To achieve adequate integration of data, numerous factors had to be considered; these are cited in footnotes that generally accompany the tables and figures of this report. In some cases, a more thorough explanation is provided in the text.

Each individual chapter details the assumptions on which waste inventories and projections are based, but some of the broader assumptions are mentioned here and are listed in Table 0.2. For the commercial fuel cycle, the spent fuel and waste projections depend upon the nuclear power growth scenario. The commercial fuel cycle waste projections reported in this document assume a reference projection of nuclear power growth and no spent fuel reprocessing. The reference nuclear power electrical growth projection (and associated discharged spent fuel schedule) used throughout this report is the 1990 DOE/EIA "No New Orders" Case.[8] In addition, this document also includes a set of nuclear capacity and spent fuel projections associated with the 1990 DOE/EIA "Lower Reference" Case to illustrate, for planning purposes, a conservative upper bound of commercial nuclear power growth.[8,9] The No New Orders and Lower Reference spent fuel and power capacity projection cases are each based on a unique set of assumptions involving nuclear electricity generation growth, reactor fuel burnup levels, reactor construction schedules, and reactor operating lifetimes and capacity factors.

Detailed information about reactors already built, being built, or planned in the United States for domestic use or export as of December 31, 1989, is provided in report DOE/OSTI-8200-R53 (ref. 10). This document contains a comprehensive listing of all domestic reactors as categorized by primary function or purpose: civilian, production, military, export, and critical assembly.

The data for total waste inventories (which comprise historical data) are obviously less accurate than the values recorded for recent waste additions. The number of digits used in reporting these values is generally greater than justified in terms of numerical significance, but this proves useful and necessary for bookkeeping purposes. In some cases, the values cited are significantly different from those previously reported. This is generally a result of improved estimates, new measurements, or redefinition of terms. Explanations are given in such cases. Many of the comments received during the final review stage of this report deal with changes that have occurred after December 31, 1989 – some as recently as mid-October 1990. These changes are generally cited in footnotes.

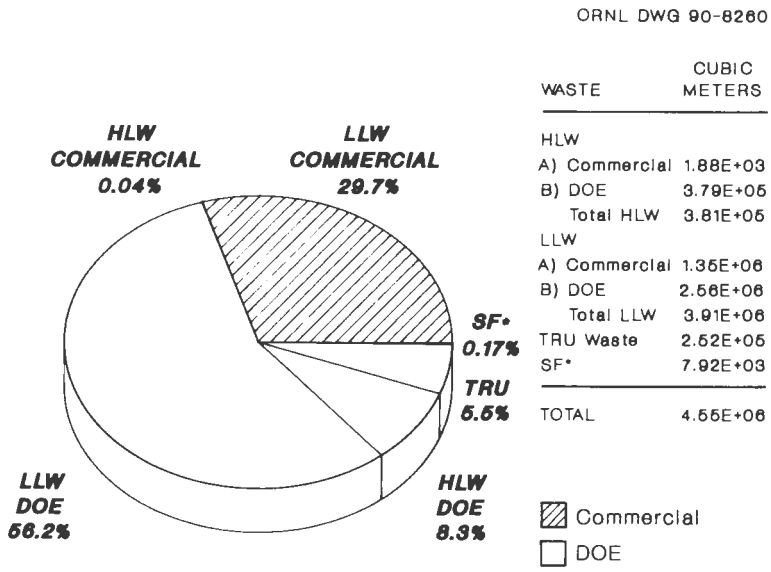
For the sake of brevity, many of the figures and tables of this report use the FORTRAN exponential (E) notation. As examples of this notation, the constant 1.234E+2 means 1.234×10^2, or 123.4; and 1.234E-4 means 1.234×10^{-4}, which is 0.0001234.

It should be noted that waste volumes accumulate with time by conventional addition, while total radioactivity and total heat do not, because radionuclides decay to nonradioactive, stable isotopes. For example, in recent years the annual additions to the inventory of LWR spent fuel measured in curies equal approximately one-half the total curies of spent fuel in inventory in any one year. However, the increase in total curies of spent fuel in inventory from one year to the next is generally only a small fraction of the total inventory. The rapid decay of short-lived isotopes in spent fuel during the first years after the fuel is removed from the reactor accounts for this effect. In this report, radionuclide decay is fully accounted for using a simplified version of the ORIGEN2 code[11] for radionuclide decay calculations.

The primary purpose of this document is to report U.S. spent fuel and radioactive waste inventories, projections, and characteristics. A few graphical presentations and summary tables are included in this chapter to provide a broad overview. Figures 0.1 and 0.2, respectively, show the volumes and activities of commercial and DOE wastes and spent fuel accumulated through 1989. Annual volume and radioactivity projections for various DOE and commercial wastes and spent fuel are shown in Figs. 0.3 and 0.4, respectively. These results exclude contributions from uranium mill tailings, wastes from commercial LWR decontamination and decommissioning (D&D) activities, and wastes from DOE environmental restoration activities. In addition, the spent fuel projections in Figs. 0.3 and 0.4 exclude DOE fuel to be reprocessed. The commercial projections represent fuel cycle requirements without reprocessing. Cumulative waste projections are shown in Figs. 0.5 and 0.6. These results exclude contributions from uranium mill tailings, commercial power reactor D&D wastes, and DOE environmental restoration wastes. The projections of Figs. 0.5 and 0.6 include HLW glass but exclude DOE fuel to be reprocessed.

The major assumptions used in preparation of this report are given in Table 0.2. These include the projection time frame and specific assumptions used for estimating government (DOE) and commercial waste projections.

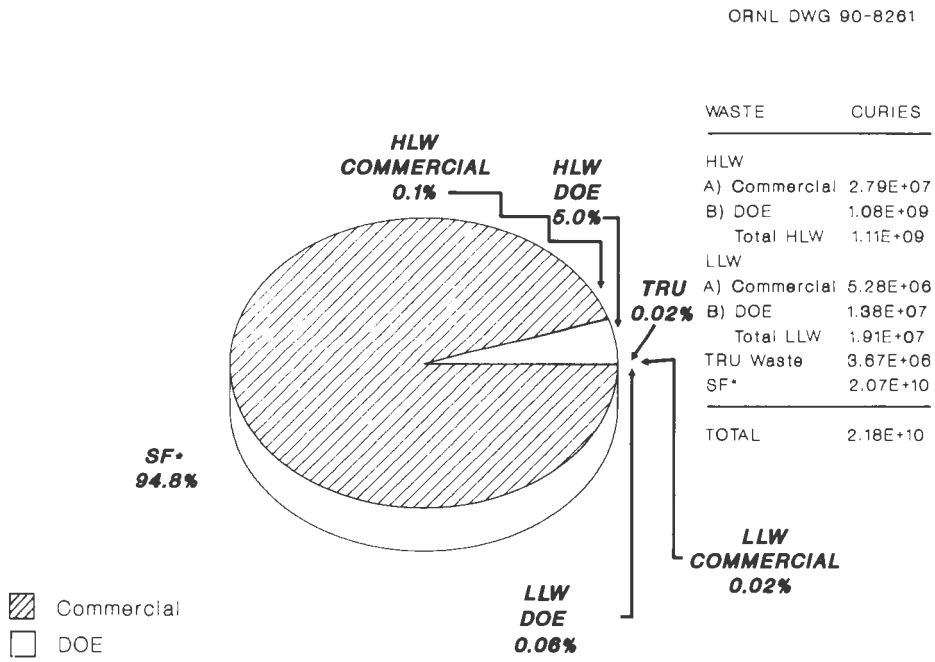
Summaries of spent fuel and radioactive waste inventories and projections are provided in Tables 0.3 and 0.4. In general, material to be sent to research and development (R&D) facilities or to the national geologic repository for spent fuel and HLW is still listed in each individual site's inventory.



WASTE	CUBIC METERS
HLW	
A) Commercial	1.88E+03
B) DOE	3.79E+05
Total HLW	3.81E+05
LLW	
A) Commercial	1.35E+06
B) DOE	2.56E+06
Total LLW	3.91E+06
TRU Waste	2.52E+05
SF*	7.92E+03
TOTAL	4.55E+06

*Includes spacing between fuel assembly rods.
Does not include DOE spent fuel to be reprocessed.

Fig. 0.1. Volumes of commercial and DOE wastes and spent fuel accumulated through 1989.



WASTE	CURIES
HLW	
A) Commercial	2.79E+07
B) DOE	1.08E+09
Total HLW	1.11E+09
LLW	
A) Commercial	5.28E+06
B) DOE	1.38E+07
Total LLW	1.91E+07
TRU Waste	3.67E+06
SF*	2.07E+10
TOTAL	2.18E+10

*Does not include DOE spent fuel to be reprocessed.

Fig. 0.2. Radioactivities of commercial and DOE wastes and spent fuel accumulated through 1989.

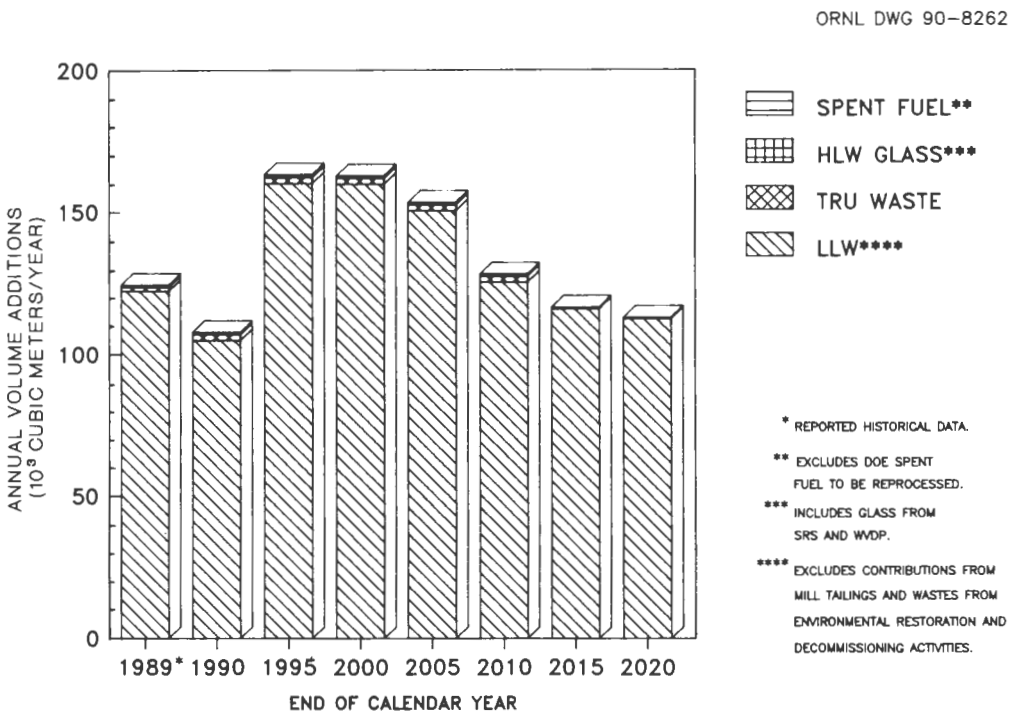


Fig. 0.3. Projections of annual volume additions for various wastes and spent fuel – DOE and commercial fuel cycle.

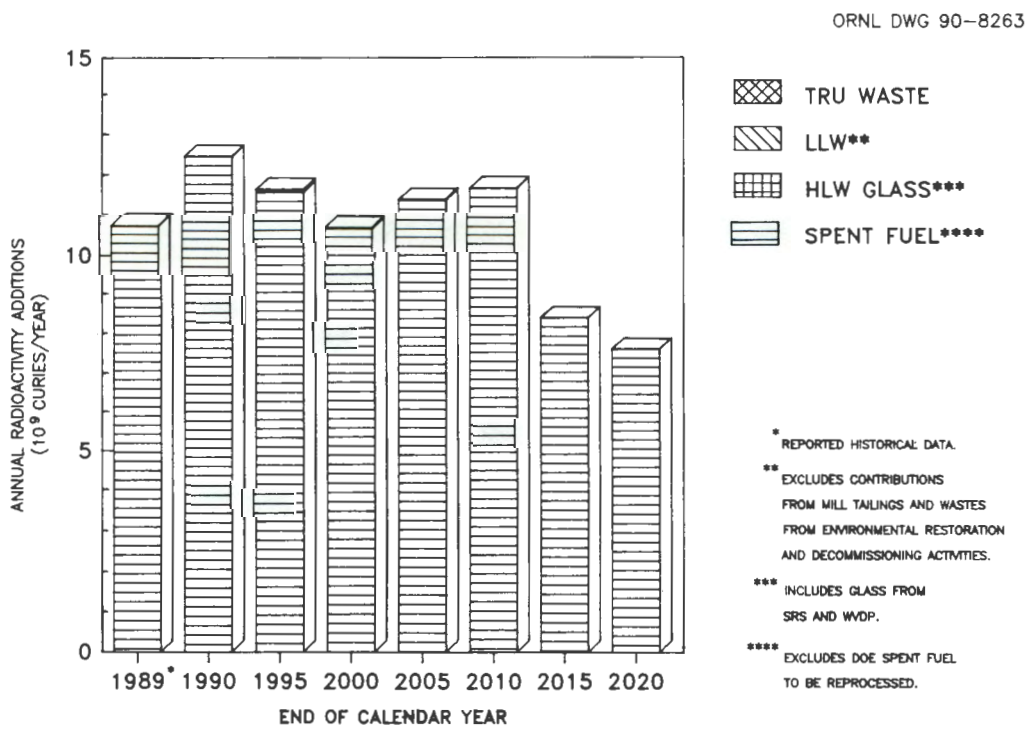


Fig. 0.4. Projections of annual radioactivity additions for various wastes and spent fuel – DOE and commercial fuel cycle.

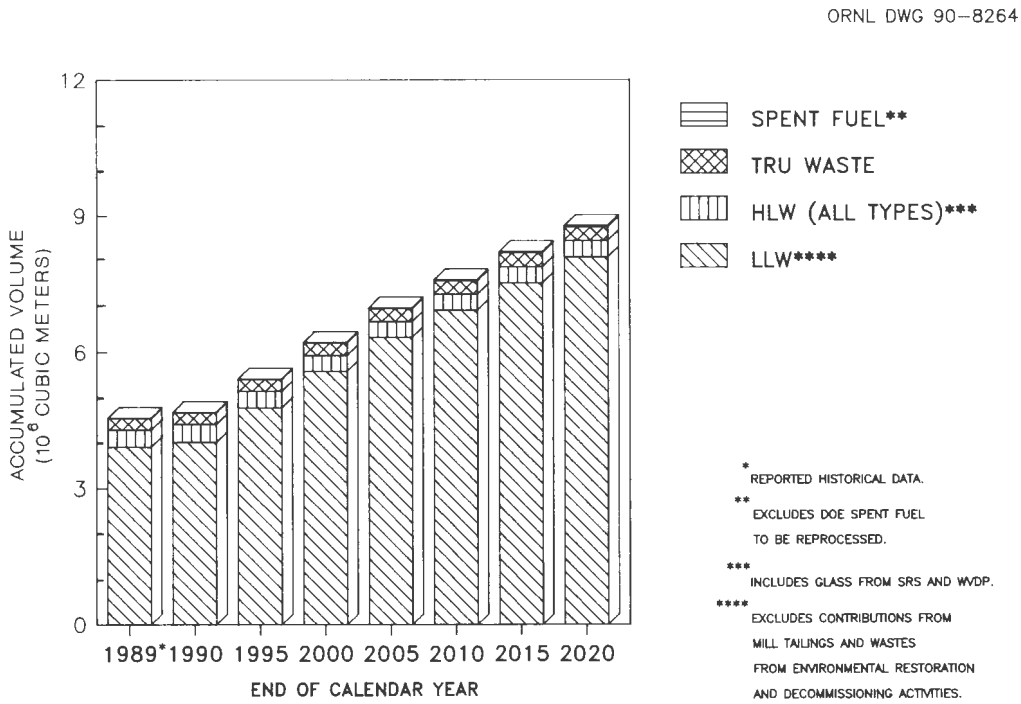


Fig. 0.5. Projections of accumulated volumes for various wastes and spent fuel – DOE and commercial fuel cycle.

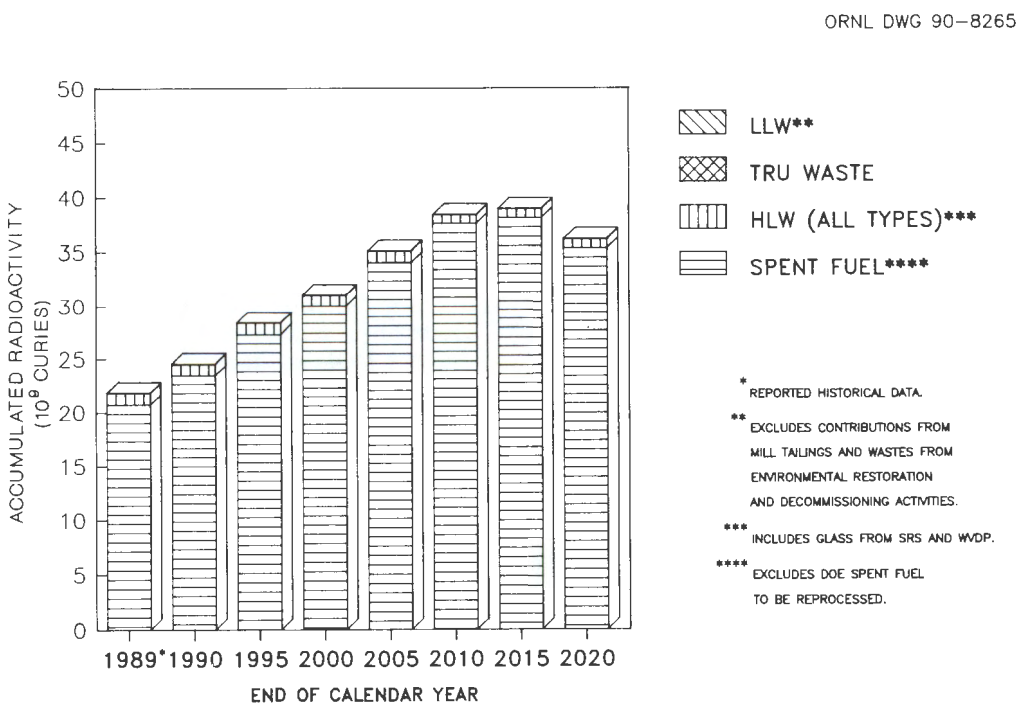


Fig. 0.6. Projections of accumulated radioactivity for various wastes and spent fuel – DOE and commercial fuel cycle.

0.4 CHAPTER OVERVIEWS

A brief summary of each chapter in this report is presented in the following paragraphs.

0.4.1 Spent Fuel

Chapter 1 of this report presents national data on the quantities of permanently discharged spent fuel from commercial nuclear power reactors. Historical data on commercial spent fuel inventories[12] are reported along with two sets of DOE/EIA projections,[9] the No New Orders and Lower Reference cases. The No New Orders Case is the baseline commercial scenario used throughout this report to make waste projections. In contrast, the Lower Reference Case represents a conservative upper limit of spent fuel projections. For the projection period considered in this report (1990–2020), the No New Orders Case assumes that no new reactors will be ordered.

Government spent fuel inventories that are not scheduled for reprocessing are reported in Chapter 8. These include various types of research reactor spent fuel which are stored at the SRS and the INEL.

In this report, the mass of discharged spent fuel is measured in metric tons of initial heavy metal (MTIHM). The term "initial heavy metal" refers to the original mass of the actinide elements of the fuel, most of which is uranium. (Elements of the actinide group are those with atomic numbers greater than 89.)

0.4.2 High-Level Waste

The inventories of HLW in storage at the end of 1989 and projected through the year 2020 are given in Chapter 2. The waste forms include liquid, sludge, salt cake, slurry, calcine, precipitate, zeolite, glass, and capsules of separated strontium and cesium. Vitrified defense HLW is projected after the startup of the Defense Waste Processing Facility (DWPF) at Savannah River in 1992. Projections of vitrified civilian HLW are also given for the WVDP. Projections recently made of the number of canisters containing the final immobilized form for the DOE HLW at Hanford and the INEL are also reported. Locations, volumes, and radioactivities of HLW are also given in Chapter 2.

0.4.3 TRU Waste

Inventories of TRU waste and projected quantities through the year 2020 are presented in Chapter 3, along with waste volumes, masses of the contained TRU waste elements, and locations. Prior to 1970, waste disposal procedures did not require segregation of TRU waste from LLW, and a considerable volume of LLW that contained TRU elements was buried in shallow trenches and pits at DOE sites. Transuranic waste was buried at six DOE sites until 1970, mostly at western locations.

In 1970, the U.S. Atomic Energy Commission (AEC) began retrievable storage of all government waste containing TRU radioactivity concentrations greater than 10 nCi/g. About 2% of this stored waste requires remote handling due to beta-gamma activity from fission products. Present inventories of TRU waste are virtually all from government operations. In 1984, DOE revised the minimum radioactivity concentration level for TRU waste from greater than 10 nCi/g to greater than 100 nCi/g. This redefinition, as well as the development of instrumentation to detect these low levels of radioactivity, has reduced the volume of TRU waste in retrievable storage. As the waste is assayed, some fraction of it will be reclassified to other waste categories. The forecasted effect of this reclassification is provided in Chapter 3.

0.4.4 Low-Level Waste

Commercial fuel cycle LLW is generated from the conversion of yellowcake to UF_6, the isotopic enrichment of this UF_6, fuel fabrication, and reactor operation. Low-level waste also results from commercial operations by private organizations that are licensed to use radioactive materials. These include institutions and industries engaged in research and various medical and industrial activities. Government LLW is similar in nature to the industrial and institutional (I/I) waste and the commercial fuel cycle LLW.

LLW inventories are reported only for solid wastes that are either buried or ready for disposal. This report does not discuss solid LLW in storage, liquid and gaseous wastes, nor inventories of LLW contaminated soils (which may be identified by environmental restoration activities).

A wide variety of radionuclides are found in LLW. Natural and depleted uranium isotopes and their daughters dominate in the conversion, enrichment, and fuel fabrication steps of the nuclear fuel cycle. Reactor operations produce LLW containing mostly activation products and fission products. A significant fraction of institutional LLW that is shipped to disposal sites is contaminated with small quantities of ^{3}H and ^{14}C.

By the end of 1989, approximately 65% of the cumulative volume of disposed LLW resulted from various DOE activities. The remaining 35% resulted from domestic commercial activities. During 1989, 38% of the volume of LLW disposed resulted from commercial activities. Approximately 73% of the annual commercial portion resulted from fuel cycle activities and reactor operations, while the remaining 27% resulted from I/I activities. In the future, these ratios may change according to the number of operating power reactors. Data for LLW from commercial and government activities are given in Chapter 4 and Appendix A.

0.4.5 Commercial Uranium Mill Tailings

Current inventories and projections of tailings from commercial uranium mill operations are summarized in

Chapter 5. Twenty-six licensed uranium mills have accumulated tailings from their operations. Half of these mills have both commercial and government tailings. By the end of 1989, only four of the NRC-licensed mills were still active. To date, about 90% of all domestic uranium has been produced by conventional mining and milling methods, from which these tailings derive. The remainder has been obtained via in situ leaching, recovery from mine water, recovery from copper/vanadium dump leach liquor, and recovery from wet-process phosphoric acid effluents. Projections of uranium mill tailings are based on commercial fuel cycle requirements, adjusted for foreign imports, as specified by the DOE/EIA No-New-Orders-Case projection of commercial reactor power growth. Tailings from the now-inactive mills that produced uranium only for government operations are classified as environmental restoration wastes (see Chapter 6).

0.4.6 Environmental Restoration Wastes

The DOE Office of Environmental Restoration and Waste Management (DOE/EM) oversees the assessment and cleanup (environmental restoration) of inactive waste facilities at all DOE sites and some non-DOE sites for which DOE has responsibility. In recent years, waste assessment and cleanup activities have proceeded in four major program areas:

1. Uranium Mill Tailings Remedial Action Program (UMTRAP),
2. Formerly Utilized MED/AEC Sites Remedial Action Program (FUSRAP),
3. Decontamination and Decommissioning (D&D) Program, and
4. Surplus Facilities Management Program (SFMP).

An overview of each of these particular restoration programs is given below, and further details are provided in Chapter 6.

The UMTRAP is involved with stabilizing uranium mill tailings at mills that are licensed but not active. There are 25 sites in the UMTRAP, which have been categorized as high-, medium-, and low-priority sites with respect to potential health effects on the general public. The total volume of tailings and other contaminated materials at UMTRAP sites is nearly 30 million m^3. All UMTRAP wastes (depending on specific site circumstances) may be either stabilized on-site or removed to another location and stabilized.

Existing congressional legislation has identified 30 FUSRAP sites to be restored as nearly as practicable for unrestricted use. Most of these sites were used by the Manhattan Engineer District (MED) of the Manhattan Project and the AEC for work with nuclear materials. Site sizes vary considerably, from a small area within a building (e.g., a laboratory) to a large outdoor tract (such as a former storage site). Only LLW is projected, and this consists primarily of contaminated soil and building rubble. More than 95% of the projected volume of this waste is expected to originate from the states of Missouri, New Jersey, and New York.

The D&D Program oversees environmental restoration for approximately 220 radioactively contaminated, DOE-owned facilities that have been declared surplus to government missions or programs. Such facilities include shutdown production reactors, irradiated fuel reprocessing plants, and discontinued waste treatment/disposal systems. The objectives of the D&D Program are to decontaminate these facilities and eliminate any potential hazards to public health and the environment. Wastes from D&D Program activities include contaminated soil, building rubble, metal, and miscellaneous materials. Predominant radioactive waste volumes at DOE D&D Program sites are LLW and mill tailings. Some TRU wastes are also present. In Chapter 6, projections of D&D Program wastes are listed separately and do not appear in any other category of waste projections reported in this document.

The SFMP was started in 1978. Initially, this program included both civilian and DOE projects, including those of the previously described D&D Program. Currently, the SFMP solely involves a DOE civilian program that oversees environmental restoration for about 30 DOE surplus sites. The objective is to decontaminate DOE civilian program facilities sufficiently to permit other productive uses and, concurrently, to eliminate any potential hazards to public health and the environment. Wastes from SFMP activities include mill tailings, contaminated soil, building rubble, metal, and other miscellaneous materials. Most of the waste volumes include mill tailings and LLW, but some TRU waste is also collected. The mill tailings at the Monticello site in Utah comprise the largest volume of SFMP wastes. About 99% of the projected total mill tailings and LLW volume from SFMP activities are accounted for by the sites at Weldon Spring, Missouri; Niagara Falls, New York; and Monticello, Utah. In this report, projections of LLW from SFMP activities are recorded separately and do not appear in any other category of waste projections.

DOE environmental restoration goals and objectives are detailed in the 1990 Five-Year Environmental Restoration and Waste Management Plan[13] developed (and updated annually) for DOE sites. This document also provides a detailed description of the new DOE organization for environmental restoration and waste management.

0.4.7 Commercial Decommissioning Wastes

Chapter 7 presents waste projections for the decommissioning of commercial power reactors and fuel cycle facilities. The D&D activities at such installations may result in very large volumes of LLW, depending on the methods selected. The major LLW volumes will result from the decommissioning of power reactors, which will also produce a small volume of high-activity waste.

Unlike that for other waste generation activities, the timing of decommissioning operations is very uncertain, since facilities may be either decommissioned upon shutdown or put into safe storage to allow for sufficient radioactive decay before decommissioning. Chapter 7 reports a set of projected characteristics for wastes from commercial LWR decommissioning activities. These projections are based on the assumption that each power reactor is immediately decommissioned after it shuts down. To date, only a few commercial reactors have been fully decommissioned, and several have been placed in protective storage. Wastes from completed decommissioning actions have been included with existing inventories discussed in other chapters. Because of timing uncertainties, projected decommissioning wastes are not included in the projections of either LLW (Chapter 4) or wastes from environmental restoration programs (Chapter 6). Rather, decommissioning waste projections are reported separately in Chapter 7.

0.4.8 Miscellaneous Radioactive Materials

Inventories and characteristics of miscellaneous radioactive materials that may require geologic disposal are reported in Appendix C. Such materials consist mainly of permanently discharged or damaged spent fuel (pellets, rods, and other fuel assembly components) from civilian and government-sponsored nuclear programs.

0.4.9 Mixed Low-Level Waste

Current inventories and generation rates of mixed LLW from both DOE and commercial sources are summarized in Chapter 8. These wastes are comprised of mixed materials or material mixtures that are both low-level radioactively contaminated and chemically hazardous.

0.4.10 Appendixes

Several appendixes are included in this report. Appendix A is a compilation of waste flowsheets, source terms, and characteristics used for waste projections. Source terms include both quantitative and descriptive characteristics used to describe radioactive wastes. As developed and used in the IDB Program, 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 contributions of component radioisotopes per curie of radioactivity of the waste. A tabulation of the properties of important radionuclides is given in Appendix B. Data on the quantities of miscellaneous radioactive materials that may require geologic disposal are reported in Appendix C. Finally, Appendix D lists the sites and facilities referred to in this report.

0.5 REFERENCES

1. U.S. Department of Energy, Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 5, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1989).

2. U.S. Congress, Nuclear Waste Policy Act of 1982, Pub. L. 97-425, Jan. 7, 1983, as amended by the Budget Reconciliation Act for Fiscal Year 1988, Title V – Energy and Environment Programs, Pub. L. 100-203, Dec. 22, 1987.

3. 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).

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

5. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste – Waste Classification," Code of Federal Regulations, 10 CFR Part 61, Section 61.55 (1982).

6. 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.

7. C. S. Fore et al., DOE Waste Information Network: DOE/DP Hazardous and Mixed Waste Data Base – A User's Guide, DOE/HWP-15, Oak Ridge National Laboratory, Oak Ridge, Tennessee (August 1986).

8. U.S. Department of Energy, Energy Information Administration, Commercial Nuclear Power 1990: Prospects for the United States and the World, DOE/EIA-0438(90), Washington, D.C. (September 1990).

9. U.S. Department of Energy, Energy Information Administration, World Nuclear Fuel Cycle Requirements 1990, DOE/EIA-0436(90), Washington, D.C. (October 1990).

10. U.S. Department of Energy, Office of Scientific and Technical Information, Nuclear Reactors Built, Being Built, or Planned: 1989, DOE/OSTI-8200-R53, Oak Ridge, Tennessee (June 1990).

11. A. G. Croff, ORIGEN2 – A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code, ORNL-5621, Oak Ridge National Laboratory, Oak Ridge, Tennessee (July 1980).

12. U.S. Department of Energy, Energy Information Administration, Nuclear Fuel Data Form RW-859 (data as of Dec. 31, 1989).

13. U.S. Department of Energy, Environmental Restoration and Waste Management Five-Year Plan – Fiscal Years 1992–1996, DOE/S-0078P, Washington, D.C. (June 1990).

Table 0.1. Major sources of information for the IDB Program

Technical area	Responsible DOE offices	Principal contractor
Ground rules and assumptions	DOE Headquarters Office of Civilian Radioactive Waste Management Office of Environmental Restoration and Waste Management	
Spent fuel	DOE/RW Energy Information Administration Richland Operations	 Pacific Northwest Laboratory
High-level waste (HLW):		
Government	Richland Operations	Westinghouse Hanford Company
Commercial	West Valley Demonstration Project	Westinghouse (West Valley Nuclear Services)
Transuranic (TRU) waste	Albuquerque Operations Waste Isolation Pilot Plant (WIPP) Project Office	 Westinghouse (WIPP Project)
Low-level waste (LLW)		
Government	Oak Ridge Operations	Hazardous Waste Remedial Actions Program
Commercial	Idaho Operations	EG&G Idaho, Inc.
Active (licensed) mill tailings	Energy Information Administration	
Environmental restoration wastes:		
Uranium Mill Tailings Remedial Action Program	Albuquerque Operations	Jacobs Engineering Group, Inc.
Formerly Utilized Sites Remedial Action Program	Oak Ridge Operations	Bechtel National, Inc.
Surplus Facilities Management Program (civilian projects)	DOE Headquarters	Roy F. Weston, Inc.
DOE Decontamination and Decommissioning (D&D) Program	DOE Headquarters	Roy F. Weston, Inc.
Nuclear facility decommissioning wastes, principally from the following:		
Shippingport Reactor	DOE Headquarters	Roy F. Weston, Inc.
Three Mile Island-Unit 2 Reactor	Idaho Operations	GPU Nuclear Corporation
West Valley Demonstration Project	Idaho Operations	Westinghouse (West Valley Nuclear Services)
Mixed LLW (DOE sites)	Oak Ridge Operations	Hazardous Waste Remedial Actions Program

Table 0.2. Major assumptions used in this report

Projection basis

- Projections are made for the years 1990-2020

Government activities

- Level of waste generating activities remains approximately constant
- Hanford defense reprocessing plant began in 1983 and will conclude operations near the end of 1996
- HLW solidification schedules:
  - For WVDP, HLW solidification (glass production) starts in 1993 and is completed in 1995
  - For SRS, HLW solidification (glass production at the Defense Waste Processing Facility) starts in 1992. Solidification continues through 2020
  - For INEL, HLW solidification (immobilization) starts in 2012, achieves full production by 2015, and continues through 2039
  - For HANF, HLW solidification (borosilicate glass production at the Hanford Waste Vitrification Plant) starts in December 1999 and will continue through 2010
- Stored LLW and inventories of soils contaminated with LLW are not included

Commercial activities

- Projections of installed net LWR electrical capacity for the DOE/EIA No New Orders Case of ref. 8:

Year	GW(e)	Year	GW(e)	Year	GW(e)	Year	GW(e)
1990	99	1998	103	2006	104	2014	72
1991	99	1999	103	2007	103	2015	69
1992	102	2000	104	2008	103	2016	63
1993	102	2001	104	2009	102	2017	59
1994	102	2002	104	2010	100	2018	58
1995	103	2003	104	2011	96	2019	58
1996	103	2004	104	2012	91	2020	54
1997	103	2005	104	2013	82		

- Average discharge burnup of LWR spent fuel: the equilibrium cycle levels for 1989 were 27,165 MWd/MTIHM for BWRs and 35,255 MWd/MTIHM for PWRs. The DOE/EIA projections for both the No New Orders Case and the Lower Reference Case assume that burnup levels of discharged spent fuel will increase at the rate of roughly 2% per year for BWR fuel and roughly 1% per year for PWR fuel, from 1989 to 2020, at which time the equilibrium cycle discharges will level out at values of roughly 42,000 and 48,000 MWd/MTIHM for BWR and PWR fuel, respectively

- Spent fuel from commercial reactors is not reprocessed. Thus, a fuel cycle without reprocessing is assumed for all commercial projections

- Lead time (number of months prior to startup after refueling) for the following fuel cycle activities:

  - Mining and milling (15) • Conversion (12) • Enrichment (12) • Fabrication (9)

- Annual volume and radioactivity of industrial and institutional (I/I) waste for projection (1990-2020) are taken to be the same as that estimated for 1990. The radioactivity added each year is decayed as if it had the composition given in Table A.11 in Appendix A

Table 0.3. Spent fuel and radioactive waste inventories as of December 31, 1989

Waste category	TRU isotopes (kg)	Mass (MTIHM)	Volume (m^3)	Activity[a] (10^6 Ci)	Thermal power (10^3 W)
Spent fuel (commercial)					
BWRs		7,570	3,051[b]	6,148	22,500
PWRs		12,071	4,866[b]	14,593	55,700
High-level waste					
Savannah River (DOE)			122,000	599	1,674
Idaho (DOE)			12,000	68	199
Hanford (DOE)[c]			244,800	416	1,208
West Valley (commercial)			1,877	28	83
Transuranic waste (DOE)					
Buried TRU waste	771		190,837	0.21	3.3
Stored TRU waste	2,191		61,559	3.67	35.6
Stored LLW[d]	14		36,564	e	e
Low-level waste (total area utilized)					
DOE sites (267 ha)[f]			2,557,000	13.77	19.39
Commercial sites (76 ha)			1,352,000	5.28	23.78
Uranium mill tailings (commercial)					
Licensed mill sites[g]			117,600,000	e	e
Environmental restoration activities (DOE)[h]					
UMTRAP (25 sites)					
Mill tailings and other waste (permanent storage)			9,765,200	e	e
GJRAP (593 sites)					
Mill tailings			52,070[i]	e	e
FUSRAP (30 sites)					
LLW (permanent and interim storage)			190,581	e	e
D&D Program (220 sites)					
TRU waste			j	e	e
LLW			j	e	e
Mill tailings			j	e	e
SFMP (civilian projects; 30 sites)					
TRU waste			j	e	e
LLW			j	e	e
Mill tailings			j	e	e
Reactor decommissioning			k	k	k
Miscellaneous radioactive materials		254.0	e	e	e
Mixed LLW					
DOE		79,510[l]	56,022	e	e
Commercial		e	e	e	e

[a]Activity data are calculated values as of December 31, 1989.

[b]Includes volume of spacing between the fuel rods of each assembly.

[c]All tank waste has been declared HLW. However, this categorization could change after the work characterizing this waste has been completed.

[d]TRU-contaminated waste in interim storage which may be managed as LLW after retrieval and assay for certification.

[e]Information not available.

[f]ha = 1 hectare = 10,000 m^2 or 2.47 acres.

[g]Includes contributions from 26 NRC-licensed mills. At the end of 1989, only four mills were active.

[h]Unless otherwise indicated, inventories reported in this table for environmental restoration activities include only contributions from projects completed at the end of 1989.

[i]Mill tailings stabilized by the Grand Junction Remedial Action Project (GJRAP) through 1982.

[j]Should include only inventories of wastes stored at environmental restoration sites. This information is currently not available.

[k]Most of this activity has involved small test reactors. (Exceptions are the Shippingport and Three Mile Island-Unit 2 reactor facilities, whose inventories are reported in Chapter 7.) The LLW collected to date from such small reactors are included in the LLW inventories listed above.

[l]Mass of mixed LLW is expressed in metric tons (t) and includes other elements in addition to heavy metals.

Table 0.4. Current and projected cumulative quantities of radioactive waste and spent fuel

Source of material and type	End of calendar year 1989	2000	2010	2020
DOE, 10^3 m^3				
HLW				
Interim storage	379	350	349	358
Glass[a]	0	1.9	3.3	3.3
TRU[b]				
Buried	191	191	191	191
Stored	62	84	105	c
LLW	2,557	3,804	4,753	5,612
Environmental restoration activities[d]				
UMTRAP and GJRAP				
Mill tailings and other waste[e,f]	9,817	32,094	32,094	32,094
FUSRAP				
LLW[g]	191	1,419	1,452	1,452
D&D Program				
TRU waste	h	0.3	0.5	0.6
LLW[g]	h	90.8	109.5	110.0
Mill tailings	h	84.1	84.1	84.1
SFMP (civilian projects)				
TRU waste	h	2.3	2.4	2.4
LLW[g]	h	968.3	968.4	968.4
Mill tailings	h	1,529	1,529	1,529
Mixed LLW[i]	56.0	c	c	c
Miscellaneous radioactive materials, MTIHM	254.0	c	c	c
Commercial, 10^3 m^3				
LWR spent fuel, MTIHM[j] (no reprocessing)				
No New Orders Case	19,641	40,400	58,600	74,800
Lower Reference Case	19,641	40,400	58,800	80,200
Commercial HLW glass (WVDP)	0.0	0.210	0.210	0.210
LLW (no reprocessing)	1,352	1,774	2,170	2,475
D&D (LLW)[k]				
Classes A, B, and C LLW	--	7.63	18.00	601.89
Greater-than-Class-C LLW	--	0.02	0.09	3.45
Mill tailings (no reprocessing)	117,600	120,100	c	c
Mixed LLW	c	c	c	c

[a]Includes projections for glass only at SRS.

[b]Projections are updated mainly as a result of improvements in detection methods. Approximately 38% of the currently stored volume will be managed as LLW.

[c]Information not available.

[d]These activities involve environmental restoration activities performed on existing wastes. Projections are based on the scheduled completion of most restoration activities by the year 2000.

[e]Mill tailings stabilized from both GJRAP and UMTRAP activities.

[f]Includes windblown contaminated soil and stabilization material from sites that may require environmental restoration.

[g]Projected LLW volumes from environmental restoration activities are not included in the DOE LLW volumes reported above.

[h]Should include only inventories of wastes stored at environmental restoration sites. This information is currently not available. Projected data that follow are cumulatives from future environmental restoration activities.

[i]Historical (1989) inventory is based on information reported by 26 sites.

[j]Historically, spent fuel has been measured in units of mass (MTIHM) rather than units of volume. The 1989 discharged spent fuel mass is a BWR and PWR mass sum rounded to the nearest metric ton. Such rounding may result in slight differences between the spent fuel inventories and projections reported in this document and those reported by DOE/EIA.

[k]Projected D&D wastes from light-water reactors shut down after 1989. Wastes collected from historical D&D of reactors are included in the LLW inventories listed above.

ORNL-PHOTO 6293-90

Photo 1.1. The Diablo Canyon Nuclear Power Plant, two 1100-MW(e) pressurized-water reactors, located along the California coast between San Francisco and Los Angeles. (Courtesy of Pacific Gas and Electric Company, San Francisco, California.)

1. SPENT FUEL

1.1 INTRODUCTION

This chapter deals exclusively with spent fuel that has been permanently discharged from commercial LWRs and one-of-a-kind reactors and that ultimately requires geologic disposal. While the spent fuel data included in this chapter are believed to be accurate, the reader is advised that the data have not yet been totally subjected to the formal quality assurance requirements of the Office of Civilian Radioactive Waste Management.

For inventories of special fuels (DOE/civilian development programs) stored at various DOE and commercial sites as of December 31, 1989, the reader is referred to Appendix C. The special fuels listed in Appendix C do not include DOE production and naval reactor fuels that are routinely reprocessed at SRS, ICPP, and Hanford. Though presently stored indefinitely at the locations cited in Appendix C, these special fuels also may ultimately require geologic disposal. Additional commercial spent fuel information may be obtained from the DOE/EIA.

Some commercial spent fuel in inventory will be reinserted into reactors for further irradiation. However, this amount is relatively small, and the schedules for reinsertion are not always predictable. Therefore, for the purposes of this report, all spent fuel is considered permanently discharged from the reactors.

Historical inventories of LWR spent fuel have been updated through December 31, 1989.[1] The data reported in this chapter include the inventories of spent fuel stored at the WVDP and the MFRP sites in addition to those stored at the various reactor sites. The map in Fig. 1.1 shows the locations of existing and planned power reactor sites and commercial LWR spent fuel storage facilities. A list of commercial reactors is given also in report DOE/OSTI-8200-R53 (ref. 2).

Projections of nuclear capacity and spent fuel discharges are given for the years 1990–2020 for two forecast schedules, the DOE/EIA No-New-Orders-Case forecast and the DOE/EIA Lower-Reference-Case forecast, reported in refs. 3 and 4. The No-New-Orders-Case forecast projects installed capacity to increase from approximately 98 GW(e) at the end of 1989 to about 104 GW(e) by 2000, ultimately decreasing to approximately 54 GW(e) by 2020. The Lower-Reference-Case forecast predicts that the installed U.S. commercial nuclear electrical generating capacity will increase from approximately 98 GW(e) at the end of 1989 to about 104 GW(e) by 2000 and to approximately 116 GW(e) by 2020.

The reference scenarios considered for projecting accumulated spent fuel assume a fuel cycle with no reprocessing. Commercial spent fuel projections developed for the DOE/EIA No New Orders Case and the DOE/EIA Lower Reference Case are illustrated, along with historical discharge data, in Figs. 1.2–1.5. Spent fuel discharge projections for both schedules, in terms of annual mass discharged and accumulated radioactivity, are graphically illustrated in Figs. 1.2 and 1.3, respectively. A graph showing the increase in the cumulative mass of discharged spent fuel for the DOE/EIA No New Orders Case is shown in Fig. 1.4. This plot also shows both the age and mass distribution for spent fuel from 1970 to 2020. Figure 1.5 is a similar plot showing the increase in the cumulative mass of discharged spent fuel for the DOE/EIA Lower Reference Case.

DOE/EIA projections for both the No New Orders Case and the Lower Reference Case assume that burnup levels of discharged spent fuel will increase from their current average levels of 21,532 and 32,261 MWd/MTIHM for BWR and PWR fuel, respectively, at the rate of about 3.2% per year for BWR fuel and about 2.5% per year for PWR fuel. This increase in burnup is projected to occur from 1989 to 2010 for BWR fuel and from 1989 to 2005 for PWR fuel, at which times the equilibrium cycle discharges will level out at values of roughly 42,000 and 48,000 MWd/MTIHM for BWR and PWR fuel, respectively. The final cycle discharges will be somewhat lower because most of the final cycle cores will not have achieved the projected design burnups. Figure 1.6 graphically illustrates how the activity and thermal power of BWR and PWR spent fuels vary with burnup and time from discharge.[5]

1.2 INVENTORIES AND PROJECTIONS

The total inventory of commercial spent fuel in storage at the WVDP site, the MFRP, and the reactor sites, as of December 31, 1989, amounted to 19,641 MTIHM. Of this total amount, 27 MTIHM are in

COMMERCIAL NUCLEAR POWER REACTORS IN THE UNITED STATES

31 DECEMBER 1989

NUCLEAR GENERATING UNIT PROFILE
31 December 1989

Status	No.	MD Capacity* net MW(e)	Design, electrical power net MW(e)
■ Full-power license	107	95,290.0	96,927.0
▲ Low-power license	1	1,198.0	1,198.0
Shut down under review	4	3,865.0	3,850.0
s Standby	1	860.0	860.0
● Under active construction	4	0.0	4,630.0
Construction deferred/halted	6	0.0	7,433.0
Total	123	101,213.0	114,898.0

*Maximum Dependable Capacity or Design Electrical Rating

Because of space limitations, symbols do not reflect precise locations.

DOE/OSTI-8200-R53 (Suppl.)
(DE90008254)

Office of Scientific and Technical Information
U.S. Department of Energy
Revised December 31, 1989
From *Nuclear Reactors Built, Being Built, or Planned*
(DOE/OSTI-8200-R53)

Fig. 1.1. Locations of existing and planned commercial reactors as of December 31, 1989.

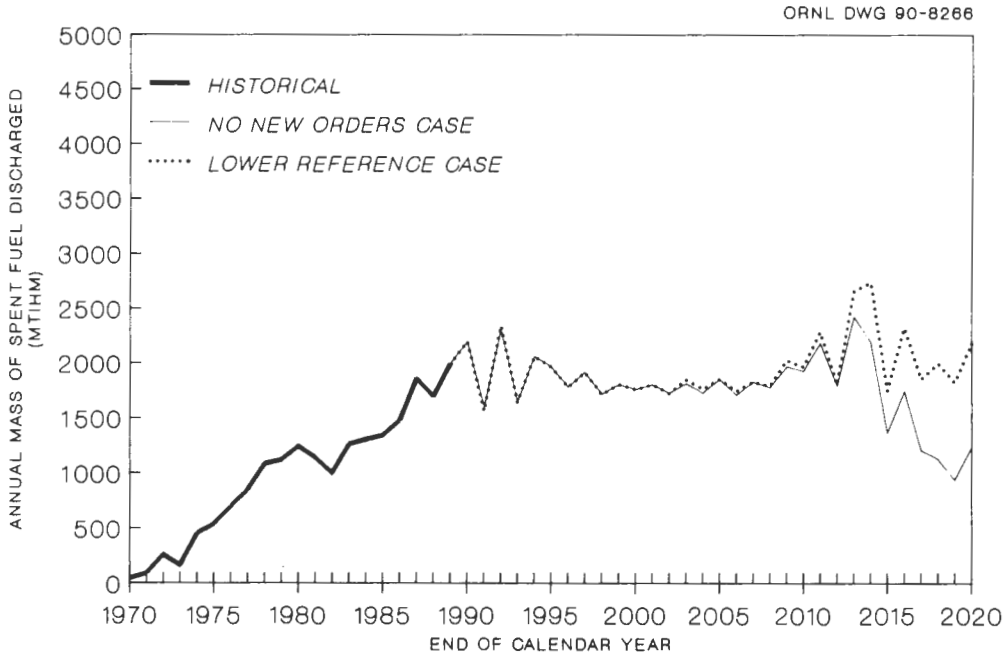


Fig. 1.2. Projected mass (MTIHM) of annual commercial spent fuel discharges for the DOE/EIA No New Orders and Lower Reference cases.

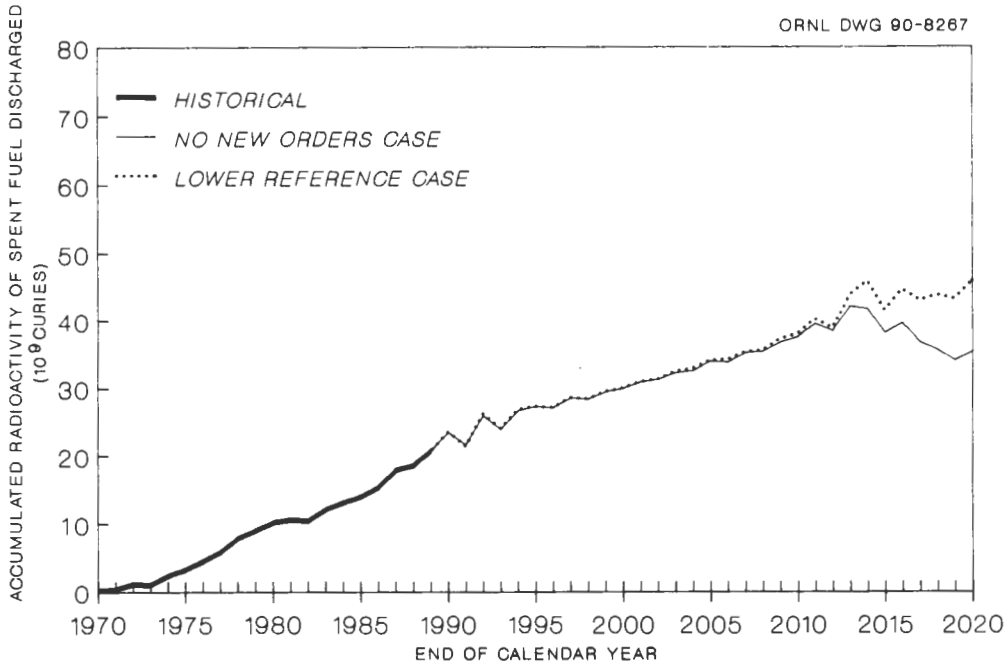


Fig. 1.3. Projected accumulated radioactivity of commercial spent fuel discharges for the DOE/EIA No New Orders and Lower Reference cases.

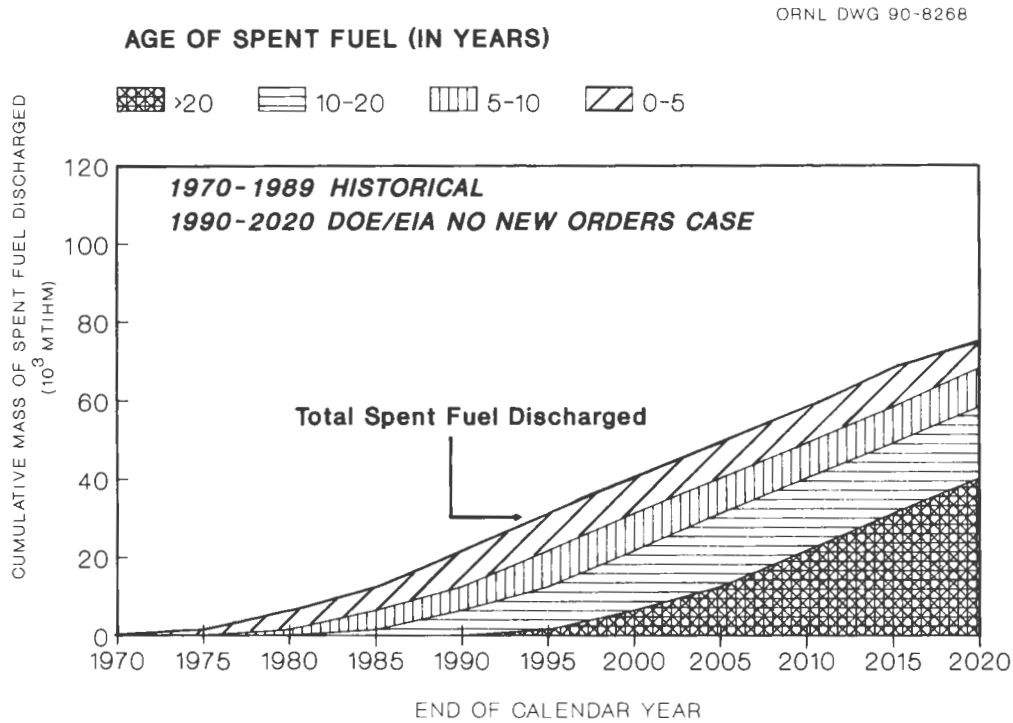


Fig. 1.4. Projected cumulative mass (MTIHM) of commercial spent fuel discharges for the DOE/EIA No New Orders Case.

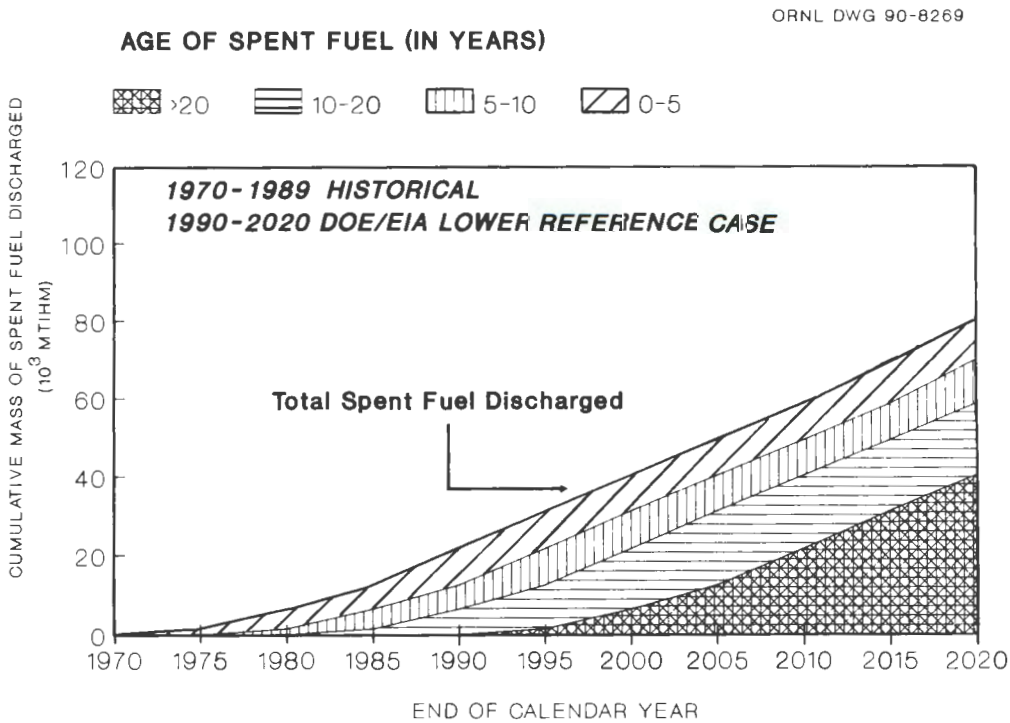


Fig. 1.5. Projected cumulative mass (MTIHM) of commercial spent fuel discharges for the DOE/EIA Lower Reference Case.

ORNL DWG 86-332

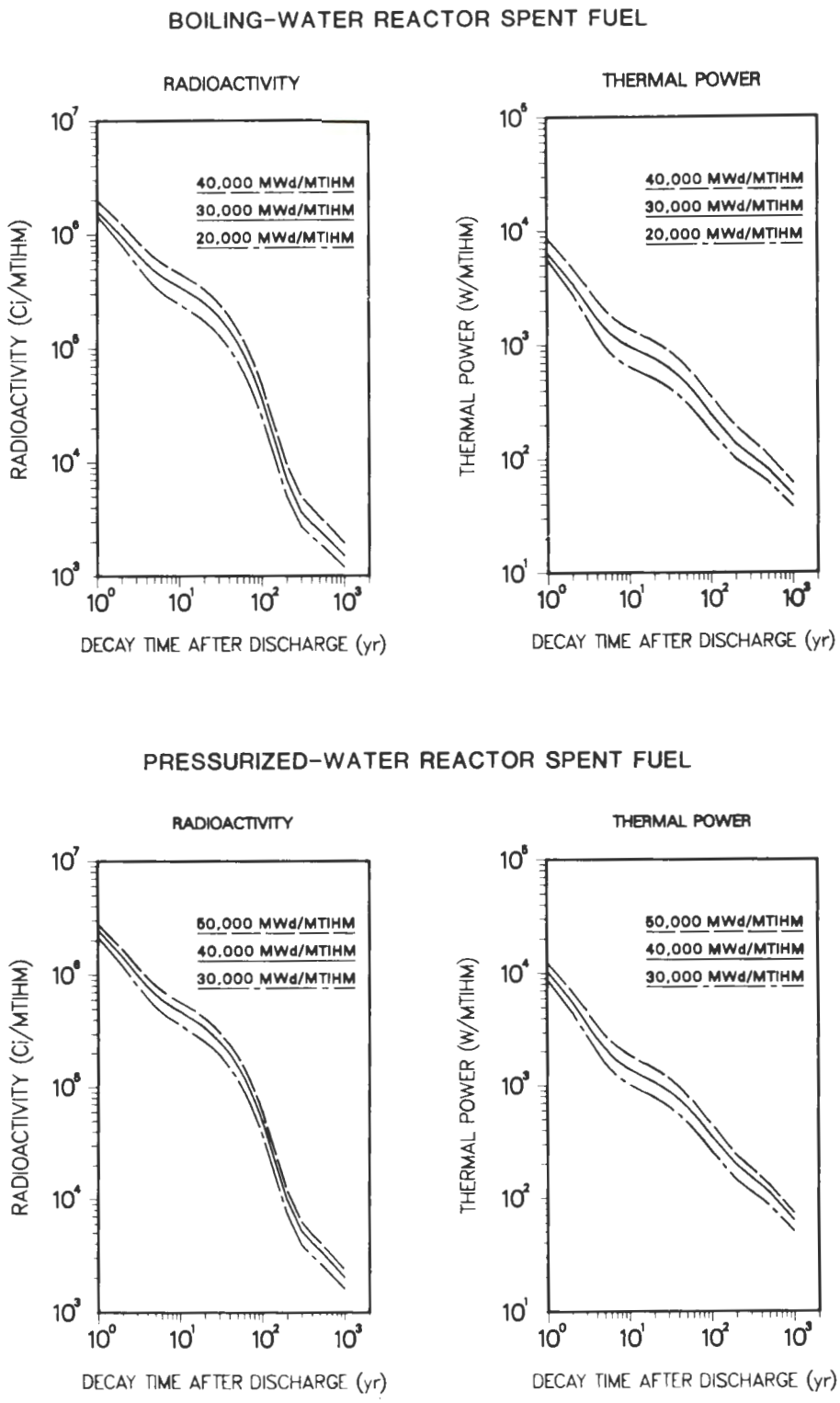


Fig. 1.6. Radioactivity and thermal power of 1 metric ton of heavy metal of BWR and PWR spent fuel as a function of burnup and time from reactor discharge.

storage at the WVDP site[6] and 674 MTIHM are in storage at the MFRP.[1] The remainder is stored at the reactor sites. These inventories do not include the spent fuel reprocessed at the WVDP site when the facility was operated as a fuel reprocessing plant. Additional information on WVDP spent fuel inventories is given in Chapter 7, Table 7.9. Details concerning the spent fuel reprocessed at West Valley may be obtained from ref. 7.

A BWR/PWR breakdown of the electric power generating capacity for both the No-New-Orders-Case forecast and the Lower-Reference-Case forecast is given in Table 1.1, along with historical reactor capacity data. Table 1.2 gives the projected cumulative mass of commercial spent fuel discharges associated with the DOE/EIA capacity growth scenarios of Table 1.1. The historical and projected buildups of permanently discharged BWR and PWR spent fuel mass, radioactivity, and thermal power are given for the DOE/EIA No New Orders Case in Table 1.3 and for the DOE/EIA Lower Reference Case in Table 1.4. Projections of the number of permanently discharged BWR and PWR spent fuel assemblies for the DOE/EIA No New Orders Case and Lower Reference Case are given in Tables 1.5 and 1.6, respectively.

The historical and projected mass of spent fuel discharged from a one-of-a-kind reactor, the Fort St. Vrain HTGR,[8] is given in Table 1.7. All of the fuel discharged from the Fort St. Vrain reactor is located at the ICPP (see Table C.6 in Appendix C).

1.3 CHARACTERIZATION

Reference characteristics of BWR and PWR fuel assemblies, obtained from refs. 9 and 10, were used for this report. These characteristics are summarized in Table 1.8. Fuel assembly structural material masses and compositions, nonactinide fuel impurities, and other physical and irradiation characteristics of LWR spent fuel are discussed in ref. 11. More detailed information on spent fuel characteristics may be found in ref. 12. The BWR and PWR spent fuel annually discharged has a broad range of burnup levels, as illustrated in Tables 1.9 and 1.10, respectively. The mass, radioactivity, and thermal power of the nuclides contained in all stored domestic commercial LWR spent fuel as of December 31, 1989, are listed in Table A.4 in Appendix A.

1.4 REFERENCES

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11. A. G. Croff et al., Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code, ORNL/TM-6051, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1978).

12. U.S. Department of Energy, Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation, DOE/RW-0184, Vols. 1–8, Oak Ridge National Laboratory, Oak Ridge, Tennessee (December 1987).

Table 1.1. Historical and projected installed LWR electric power generating capacity for the DOE/EIA No New Orders and Lower Reference cases[a]

End of calendar year	Historical capacity [GW(e)]			End of calendar year	No New Orders Case projected capacity[b] [GW(e)]			Lower Reference Case projected capacity[c] [GW(e)]		
	BWR	PWR	Total		BWR	PWR	Total	BWR	PWR	Total
1960	0.1	0.2	0.3	1990	31.9	67.4	99.3	31.9	67.4	99.3
1961	0.1	0.2	0.3	1991	31.9	67.4	99.3	31.9	67.4	99.3
1962	0.1	0.2	0.4	1992	31.9	69.7	101.6	31.9	69.7	101.6
1963	0.1	0.2	0.4	1993	31.9	69.7	101.6	31.9	69.7	101.6
1964	0.1	0.2	0.4	1994	31.9	69.7	101.6	31.9	69.7	101.6
1965	0.1	0.2	0.4	1995	31.9	70.9	102.8	31.9	70.9	102.8
1966	0.1	0.2	0.4	1996	31.9	70.9	102.8	31.9	70.9	102.8
1967	0.1	1.3	1.4	1997	31.9	70.9	102.8	31.9	70.9	102.8
1968	0.2	1.2	1.4	1998	31.9	70.9	102.8	31.9	70.9	102.8
1969	0.8	1.7	2.6	1999	31.9	70.9	102.8	31.9	70.9	102.8
1970	2.9	2.9	5.8	2000	31.9	71.9	103.8	31.9	71.9	103.8
1971	4.3	3.7	8.0	2001	31.9	71.9	103.8	31.9	73.1	105.1
1972	7.0	6.5	13.5	2002	31.9	71.9	103.8	31.9	73.1	105.1
1973	8.1	14.1	22.1	2003	31.9	71.9	103.8	31.9	73.1	105.0
1974	13.3	19.4	32.7	2004	31.9	71.9	103.8	31.9	73.1	105.0
1975	15.0	23.3	38.3	2005	31.9	71.9	103.8	31.9	73.1	105.0
1976	16.8	27.9	44.7	2006	31.9	71.9	103.8	31.9	73.1	105.0
1977	16.8	30.4	47.2	2007	31.9	70.9	102.8	33.2	72.1	105.3
1978	17.6	32.2	49.8	2008	31.9	70.9	102.8	33.2	72.1	105.3
1979	17.6	32.2	49.8	2009	29.9	71.6	101.5	31.2	73.5	104.7
1980	17.6	34.3	51.9	2010	29.2	70.5	99.7	30.5	72.3	102.9
1981	17.6	38.6	56.2	2011	27.1	68.4	95.5	28.4	76.5	104.9
1982	18.7	40.5	59.2	2012	25.2	66.1	91.3	26.5	80.4	106.9
1983	19.7	43.6	63.3	2013	23.1	59.4	82.5	24.4	79.8	104.2
1984	24.2	45.8	70.0	2014	17.4	54.5	71.9	18.7	81.2	99.9
1985	26.8	51.7	78.5	2015	17.4	51.6	69.0	18.7	84.5	103.1
1986	28.9	55.2	84.1	2016	15.5	47.1	62.6	16.8	85.6	102.4
1987	31.8	60.8	92.6	2017	15.5	43.7	59.2	16.8	87.8	104.6
1988	31.8	63.1	94.9	2018	14.7	42.8	57.5	16.0	92.6	108.6
1989	33.8	64.1	97.9	2019	14.7	42.8	57.5	16.0	98.3	114.3
				2020	14.7	38.8	53.5	16.0	99.9	116.0

[a]Based on ref. 3.

[b]Assumes (1) that no new reactors will be ordered and (2) that a few units currently under construction will be canceled.

[c]Assumes basically the same criteria as given in footnote "b" except the case further assumes that any generating capacity lost due to reactor shutdown will be replaced.

Table 1.2. Projected cumulative mass of commercial spent fuel discharges for alternative DOE/EIA scenarios

End of calendar year	Cumulative spent fuel discharged,[a] 10^3 MTIHM	
	No New Orders Case	Lower Reference Case
1989[b]	19.6	19.6
1990	21.8	21.8
1991	23.4	23.4
1992	25.8	25.8
1993	27.4	27.4
1994	29.5	29.5
1995	31.4	31.4
1996	33.2	33.2
1997	35.1	35.1
1998	36.9	36.9
1999	38.7	38.7
2000	40.4	40.4
2001	42.2	42.2
2002	44.0	44.0
2003	45.8	45.8
2004	47.5	47.6
2005	49.4	49.4
2006	51.1	51.2
2007	52.9	53.0
2008	54.7	54.8
2009	56.6	56.8
2010	58.6	58.8
2011	60.8	61.1
2012	62.6	62.9
2013	65.0	65.6
2014	67.2	68.3
2015	68.5	70.0
2016	70.3	72.4
2017	71.5	74.2
2018	72.6	76.2
2019	73.6	78.1
2020	74.8	80.2

[a]In years prior to 2000 where the cumulative spent fuel discharge for the No New Orders Case exceeds the cumulative discharge for the Lower Reference Case, the differences between these two cases are due to slightly different assumptions made with regard to the duration of the reactor operating cycles.

[b]Reported historical data.

Table 1.3. Historical and projected mass, radioactivity, and thermal power of permanently discharged spent fuel by reactor type for the DOE/EIA No New Orders Case

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Boiling-water reactor			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.1	0.1
1970	6	16	1	11	0.0	0.0
1971	64	80	190	197	0.7	0.7
1972	142	221	431	466	1.6	1.8
1973	95	317	350	442	1.3	1.7
1974	245	561	908	1,043	3.5	4.0
1975	215	776	875	1,172	3.4	4.5
1976	299	1,075	1,167	1,585	4.6	6.0
1977	383	1,457	1,566	2,129	6.2	8.1
1978	383	1,841	1,618	2,411	6.5	9.2
1979	400	2,241	1,734	2,728	7.0	10.5
1980	620	2,860	2,685	3,887	10.9	15.0
1981	459	3,319	2,014	3,663	8.2	14.0
1982	357	3,676	1,582	3,361	6.4	12.5
1983	491	4,167	2,218	4,014	9.1	15.1
1984	462	4,630	2,077	4,148	8.5	15.4
1985	485	5,115	2,118	4,359	8.6	16.1
1986	464	5,579	1,985	4,369	8.0	15.9
1987	707	6,286	2,953	5,413	11.8	19.8
1988	537	6,822	2,367	5,167	9.6	18.8
1989	748	7,570	3,213	6,148	13.0	22.5
1990	600	8,200	2,800	6,100	11.6	22.4
1991	500	8,700	2,500	6,000	10.1	21.6
1992	700	9,500	3,400	7,000	14.1	25.8
1993	600	10,000	2,600	6,700	10.8	24.2
1994	600	10,700	2,900	7,100	12.1	25.8
1995	700	11,300	3,200	7,600	13.3	27.7
1996	600	11,900	3,000	7,700	12.4	28.0
1997	600	12,600	3,100	8,000	12.9	29.2
1998	500	13,100	2,600	7,800	10.9	28.2
1999	600	13,700	2,800	8,100	12.0	29.5
2000	600	14,200	2,800	8,300	11.8	30.0
2001	600	14,900	3,200	8,900	13.4	32.3
2002	500	15,400	2,600	8,600	10.9	31.0
2003	600	16,100	3,200	9,200	13.5	33.7
2004	500	16,600	2,700	9,100	11.4	32.8
2005	500	17,100	2,700	9,200	11.5	33.2
2006	600	17,700	2,900	9,500	12.3	34.5
2007	500	18,200	2,600	9,400	10.9	33.8
2008	700	18,900	3,300	10,200	14.0	37.2
2009	800	19,700	3,900	11,100	16.0	40.6
2010	700	20,400	3,300	10,900	13.7	39.7
2011	900	21,300	4,400	12,200	18.2	44.7
2012	600	21,900	2,800	11,100	11.6	40.0
2013	700	22,600	3,600	11,800	15.3	42.9
2014	900	23,500	4,300	12,800	17.7	46.4
2015	400	23,900	1,800	10,700	7.6	37.7
2016	400	24,300	2,100	10,600	8.9	37.1
2017	300	24,700	1,500	9,900	6.5	34.1
2018	300	25,000	1,700	9,800	7.3	34.0
2019	300	25,300	1,300	9,300	5.3	31.9
2020	300	25,500	1,400	9,200	5.9	31.8

Table 1.3 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Pressurized-water reactor			
1968	0	0				
1969	0	0				
1970	39	39	204	204	0.8	0.8
1971	26	66	146	195	0.5	0.7
1972	118	183	646	712	2.5	2.8
1973	67	250	374	582	1.5	2.2
1974	208	458	1,098	1,325	4.3	5.1
1975	322	780	1,683	2,101	6.6	8.1
1976	397	1,177	2,198	2,872	8.8	11.2
1977	467	1,643	2,660	3,672	10.7	14.4
1978	700	2,344	4,037	5,433	16.4	21.5
1979	720	3,064	4,177	6,245	17.0	24.6
1980	623	3,687	3,697	6,276	15.1	24.6
1981	683	4,370	4,067	6,937	16.6	27.0
1982	641	5,011	3,801	7,058	15.5	27.2
1983	772	5,783	4,589	8,087	18.8	31.2
1984	845	6,627	4,998	8,971	20.4	34.5
1985	858	7,486	5,182	9,641	21.3	37.0
1986	1,017	8,503	6,068	11,016	24.9	42.2
1987	1,155	9,658	6,924	12,514	28.4	48.0
1988	1,162	10,820	7,068	13,426	29.1	51.4
1989	1,251	12,071	7,553	14,593	31.0	55.7
1990	1,600	13,600	9,600	17,400	39.9	66.8
1991	1,100	14,700	6,700	15,700	27.7	59.4
1992	1,600	16,300	10,000	19,000	41.4	72.8
1993	1,100	17,400	6,900	17,300	28.9	65.2
1994	1,400	18,800	9,300	19,700	38.9	74.8
1995	1,300	20,100	8,400	19,700	35.0	74.6
1996	1,200	21,300	7,600	19,500	31.9	73.1
1997	1,300	22,600	8,500	20,600	35.7	77.7
1998	1,200	23,800	7,800	20,700	33.0	77.5
1999	1,200	25,000	8,200	21,400	34.7	80.5
2000	1,200	26,200	7,900	21,800	33.6	81.6
2001	1,200	27,300	7,700	22,000	32.8	82.4
2002	1,200	28,500	8,000	22,700	34.2	85.2
2003	1,200	29,700	7,800	23,000	33.0	86.0
2004	1,200	30,900	7,900	23,500	33.6	87.9
2005	1,300	32,200	8,700	24,800	37.1	93.0
2006	1,100	33,300	7,500	24,300	32.2	90.8
2007	1,300	34,700	8,800	25,800	37.2	96.5
2008	1,100	35,800	7,500	25,200	32.1	94.0
2009	1,200	36,900	7,800	25,700	33.3	95.8
2010	1,300	38,200	8,400	26,700	36.0	99.8
2011	1,300	39,500	8,500	27,300	35.6	101.7
2012	1,200	40,700	8,000	27,200	33.8	101.3
2013	1,700	42,400	11,000	30,500	46.0	114.4
2014	1,300	43,600	8,400	29,100	35.3	108.3
2015	1,000	44,600	6,600	27,400	27.8	100.6
2016	1,300	45,900	8,600	29,000	36.3	107.3
2017	900	46,800	5,900	26,900	24.9	98.2
2018	800	47,600	5,200	25,700	21.9	93.2
2019	700	48,300	4,600	24,700	19.5	89.2
2020	1,000	49,300	6,200	26,000	26.1	94.5

Table 1.3 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Total			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.1	0.1
1970	45	55	205	215	0.8	0.8
1971	90	145	336	391	1.3	1.5
1972	259	405	1,077	1,178	4.2	4.6
1973	162	567	724	1,024	2.8	3.9
1974	452	1,019	2,006	2,368	7.9	9.2
1975	537	1,556	2,557	3,273	10.1	12.7
1976	695	2,251	3,366	4,457	13.4	17.3
1977	850	3,101	4,225	5,801	17.0	22.6
1978	1,084	4,185	5,655	7,844	22.9	30.7
1979	1,120	5,304	5,912	8,973	24.0	35.1
1980	1,243	6,547	6,382	10,163	26.0	39.7
1981	1,141	7,689	6,081	10,599	24.9	41.0
1982	999	8,687	5,383	10,419	22.0	39.8
1983	1,263	9,950	6,808	12,102	27.9	46.3
1984	1,307	11,257	7,074	13,119	28.9	49.9
1985	1,343	12,601	7,300	13,999	29.9	53.1
1986	1,481	14,082	8,053	15,386	32.9	58.1
1987	1,862	15,944	9,876	17,927	40.3	67.9
1988	1,698	17,642	9,435	18,593	38.8	70.2
1989	1,998	19,641	10,766	20,741	44.1	78.3
1990	2,200	21,800	12,500	23,500	51.5	89.2
1991	1,600	23,400	9,100	21,600	37.9	81.0
1992	2,300	25,800	13,400	26,000	55.5	98.7
1993	1,600	27,400	9,600	23,900	39.8	89.5
1994	2,100	29,500	12,200	26,700	51.0	100.6
1995	2,000	31,400	11,600	27,300	48.3	102.4
1996	1,800	33,200	10,600	27,100	44.4	101.1
1997	1,900	35,100	11,500	28,600	48.6	106.9
1998	1,700	36,900	10,400	28,400	44.0	105.7
1999	1,800	38,700	11,000	29,500	46.7	110.0
2000	1,800	40,400	10,700	30,000	45.5	111.7
2001	1,800	42,200	10,900	30,900	46.3	114.8
2002	1,700	44,000	10,600	31,300	45.1	116.2
2003	1,800	45,800	11,000	32,300	46.6	119.7
2004	1,700	47,500	10,600	32,600	45.1	120.8
2005	1,900	49,400	11,400	34,000	48.6	126.3
2006	1,700	51,100	10,500	33,800	44.5	125.3
2007	1,800	52,900	11,300	35,200	48.2	130.4
2008	1,800	54,700	10,800	35,400	46.2	131.2
2009	2,000	56,600	11,700	36,800	49.4	136.4
2010	1,900	58,600	11,700	37,600	49.7	139.6
2011	2,200	60,800	12,800	39,500	53.9	146.4
2012	1,800	62,600	10,800	38,400	45.5	141.3
2013	2,400	65,000	14,600	42,300	61.3	157.3
2014	2,200	67,200	12,700	41,900	53.0	154.7
2015	1,400	68,500	8,400	38,100	35.4	138.3
2016	1,700	70,300	10,800	39,600	45.3	144.4
2017	1,200	71,500	7,500	36,800	31.4	132.4
2018	1,100	72,600	6,900	35,600	29.3	127.3
2019	900	73,600	5,900	34,000	24.9	121.2
2020	1,200	74,800	7,600	35,300	32.1	126.3

[a]Ref. 1 (1968–1989).
[b]Ref. 4 (1990–2020). Assumes no future reprocessing.

Table 1.4. Historical and projected mass, radioactivity, and thermal power of permanently discharged spent fuel by reactor type for the DOE/EIA Lower Reference Case

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Boiling-water reactor			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.1	0.1
1970	6	16	1	11	0.0	0.0
1971	64	80	190	197	0.7	0.7
1972	142	221	431	466	1.6	1.8
1973	95	317	350	442	1.3	1.7
1974	245	561	908	1,043	3.5	4.0
1975	215	776	875	1,172	3.4	4.5
1976	299	1,075	1,167	1,585	4.6	6.0
1977	383	1,457	1,566	2,129	6.2	8.1
1978	383	1,841	1,618	2,411	6.5	9.2
1979	400	2,241	1,734	2,728	7.0	10.5
1980	620	2,860	2,685	3,887	10.9	15.0
1981	459	3,319	2,014	3,663	8.2	14.0
1982	357	3,676	1,582	3,361	6.4	12.5
1983	491	4,167	2,218	4,014	9.1	15.1
1984	462	4,630	2,077	4,148	8.5	15.4
1985	485	5,115	2,118	4,359	8.6	16.1
1986	464	5,579	1,985	4,369	8.0	15.9
1987	707	6,286	2,953	5,413	11.8	19.8
1988	537	6,822	2,367	5,167	9.6	18.8
1989	748	7,570	3,213	6,148	13.0	22.5
1990	600	8,200	2,800	6,100	11.6	22.4
1991	500	8,700	2,500	6,000	10.1	21.6
1992	700	9,500	3,400	7,000	14.1	25.8
1993	600	10,000	2,600	6,700	10.8	24.2
1994	600	10,700	2,900	7,100	12.1	25.8
1995	700	11,300	3,200	7,600	13.3	27.7
1996	600	11,900	3,000	7,700	12.4	28.0
1997	600	12,600	3,100	8,000	12.9	29.2
1998	500	13,100	2,600	7,800	10.9	28.2
1999	600	13,700	2,800	8,100	12.0	29.5
2000	600	14,200	2,800	8,300	11.8	30.0
2001	600	14,900	3,200	8,900	13.4	32.3
2002	500	15,400	2,600	8,600	10.9	31.0
2003	600	16,100	3,200	9,200	13.5	33.7
2004	500	16,600	2,700	9,100	11.4	32.8
2005	500	17,100	2,700	9,200	11.5	33.2
2006	600	17,700	2,900	9,500	12.3	34.5
2007	500	18,200	2,600	9,400	10.9	33.8
2008	700	18,900	3,300	10,200	14.0	37.2
2009	800	19,700	3,900	11,100	16.0	40.6
2010	700	20,400	3,400	11,100	14.3	40.3
2011	1,000	21,400	4,600	12,400	19.0	45.6
2012	600	22,000	2,800	11,200	11.6	40.3
2013	800	22,800	3,900	12,100	16.2	43.9
2014	900	23,700	4,300	12,900	17.7	46.8
2015	400	24,100	2,000	11,000	8.6	38.9
2016	500	24,600	2,500	11,100	10.4	39.0
2017	300	24,900	1,400	10,000	6.0	34.5
2018	300	25,200	1,700	9,900	7.3	34.4
2019	400	25,600	1,700	9,900	7.3	34.2
2020	200	25,800	1,200	9,300	5.1	31.9

Table 1.4 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Pressurized-water reactor			
1968	0	0				
1969	0	0				
1970	39	39	204	204	0.8	0.8
1971	26	66	146	195	0.5	0.7
1972	118	183	646	712	2.5	2.8
1973	67	250	374	582	1.5	2.2
1974	208	458	1,098	1,325	4.3	5.1
1975	322	780	1,683	2,101	6.6	8.1
1976	397	1,177	2,198	2,872	8.8	11.2
1977	467	1,643	2,660	3,672	10.7	14.4
1978	700	2,344	4,037	5,433	16.4	21.5
1979	720	3,064	4,177	6,245	17.0	24.6
1980	623	3,687	3,697	6,276	15.1	24.6
1981	683	4,370	4,067	6,937	16.6	27.0
1982	641	5,011	3,801	7,058	15.5	27.2
1983	772	5,783	4,589	8,087	18.8	31.2
1984	845	6,627	4,998	8,971	20.4	34.5
1985	858	7,486	5,182	9,641	21.3	37.0
1986	1,017	8,503	6,068	11,016	24.9	42.2
1987	1,155	9,658	6,924	12,514	28.4	48.0
1988	1,162	10,820	7,068	13,426	29.1	51.4
1989	1,251	12,071	7,553	14,593	31.0	55.7
1990	1,600	13,600	9,600	17,400	39.9	66.8
1991	1,000	14,700	6,500	15,500	26.8	58.5
1992	1,600	16,300	10,200	19,100	42.3	73.4
1993	1,100	17,400	6,900	17,300	28.9	65.3
1994	1,400	18,800	9,300	19,700	38.9	74.8
1995	1,300	20,100	8,400	19,700	35.0	74.6
1996	1,200	21,300	7,600	19,500	31.9	73.1
1997	1,300	22,600	8,500	20,600	35.7	77.7
1998	1,200	23,800	7,800	20,700	33.0	77.5
1999	1,200	25,000	8,200	21,400	34.7	80.5
2000	1,200	26,200	7,900	21,800	33.6	81.6
2001	1,200	27,300	7,700	22,000	32.8	82.4
2002	1,200	28,500	8,000	22,700	34.2	85.2
2003	1,200	29,800	8,000	23,200	33.8	86.8
2004	1,200	31,000	8,100	23,800	34.6	89.1
2005	1,300	32,300	8,700	24,900	37.1	93.4
2006	1,200	33,500	7,800	24,600	33.2	92.0
2007	1,300	34,800	8,800	25,900	37.2	97.0
2008	1,100	35,900	7,600	25,400	32.6	94.8
2009	1,200	37,100	8,200	26,200	35.0	97.9
2010	1,300	38,400	8,400	26,900	36.0	100.7
2011	1,300	39,700	8,800	27,800	37.1	103.8
2012	1,200	40,900	8,100	27,600	34.2	102.6
2013	1,900	42,800	12,100	31,800	50.5	119.6
2014	1,800	44,600	11,800	33,000	49.2	123.9
2015	1,300	46,000	8,600	30,700	35.8	113.8
2016	1,800	47,800	11,800	33,600	49.4	125.6
2017	1,600	49,300	10,200	33,100	42.6	123.0
2018	1,700	51,000	10,800	34,000	45.5	126.7
2019	1,500	52,500	9,700	33,500	41.0	124.4
2020	1,900	54,400	12,700	36,600	53.3	137.3

Table 1.4 (continued)

End of calendar year	Mass,[a,b] MTIHM		Radioactivity, 10^6 Ci		Thermal power, 10^6 W	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Total			
1968	1	1	1	1	0.0	0.0
1969	10	10	39	39	0.1	0.1
1970	45	55	205	215	0.8	0.8
1971	90	145	336	391	1.3	1.5
1972	259	405	1,077	1,178	4.2	4.6
1973	162	567	724	1,024	2.8	3.9
1974	452	1,019	2,006	2,368	7.9	9.2
1975	537	1,556	2,557	3,273	10.1	12.7
1976	695	2,251	3,366	4,457	13.4	17.3
1977	850	3,101	4,225	5,801	17.0	22.6
1978	1,084	4,185	5,655	7,844	22.9	30.7
1979	1,120	5,304	5,912	8,973	24.0	35.1
1980	1,243	6,547	6,382	10,163	26.0	39.7
1981	1,141	7,689	6,081	10,599	24.9	41.0
1982	999	8,687	5,383	10,419	22.0	39.8
1983	1,263	9,950	6,808	12,102	27.9	46.3
1984	1,307	11,257	7,074	13,119	28.9	49.9
1985	1,343	12,601	7,300	13,999	29.9	53.1
1986	1,481	14,082	8,053	15,386	32.9	58.1
1987	1,862	15,944	9,876	17,927	40.3	67.9
1988	1,698	17,642	9,435	18,593	38.8	70.2
1989	1,998	19,641	10,766	20,741	44.1	78.3
1990	2,200	21,800	12,500	23,500	51.5	89.2
1991	1,600	23,400	8,900	21,400	37.0	80.1
1992	2,300	25,800	13,600	26,200	56.4	99.3
1993	1,600	27,400	9,600	24,000	39.8	89.6
1994	2,100	29,500	12,200	26,800	51.0	100.6
1995	2,000	31,400	11,600	27,300	48.3	102.4
1996	1,800	33,200	10,600	27,100	44.4	101.1
1997	1,900	35,100	11,500	28,600	48.6	106.9
1998	1,700	36,900	10,400	28,400	44.0	105.7
1999	1,800	38,700	11,000	29,500	46.7	110.0
2000	1,800	40,400	10,700	30,000	45.5	111.7
2001	1,800	42,200	10,900	30,900	46.3	114.8
2002	1,700	44,000	10,600	31,300	45.1	116.2
2003	1,900	45,800	11,200	32,500	47.4	120.5
2004	1,800	47,600	10,800	32,900	46.0	121.9
2005	1,900	49,400	11,400	34,100	48.6	126.6
2006	1,700	51,200	10,700	34,200	45.6	126.6
2007	1,800	53,000	11,300	35,300	48.2	130.8
2008	1,800	54,800	10,900	35,600	46.7	132.0
2009	2,000	56,800	12,100	37,300	51.0	138.5
2010	2,000	58,800	11,900	38,000	50.3	141.0
2011	2,300	61,100	13,400	40,200	56.2	149.4
2012	1,800	62,900	10,900	38,800	45.9	143.0
2013	2,700	65,600	16,000	43,900	66.7	163.5
2014	2,700	68,300	16,100	45,900	66.9	170.7
2015	1,800	70,000	10,600	41,700	44.5	152.8
2016	2,300	72,400	14,300	44,700	59.8	164.7
2017	1,900	74,200	11,600	43,100	48.7	157.5
2018	2,000	76,200	12,500	43,900	52.9	161.2
2019	1,800	78,100	11,400	43,300	48.4	158.7
2020	2,200	80,200	13,900	45,900	58.4	169.3

[a]Ref. 1 (1968–1989).
[b]Ref. 4 (1990–2020). Assumes no future reprocessing.

Table 1.5. Projected number of permanently discharged LWR spent fuel assemblies for the DOE/EIA No New Orders Case[a]

End of calendar year	BWR		PWR		Total	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1989[b]	4,101	41,673	2,869	28,336	6,970	70,009
1990	3,500	45,200	3,600	32,000	7,200	77,200
1991	3,000	48,200	2,500	34,500	5,500	82,700
1992	4,100	52,400	3,600	38,100	7,800	90,500
1993	3,100	55,500	2,600	40,600	5,700	96,100
1994	3,500	59,000	3,300	44,000	6,900	103,000
1995	3,800	62,800	3,100	47,000	6,800	109,800
1996	3,500	66,200	2,700	49,800	6,200	116,000
1997	3,500	69,700	3,000	52,800	6,500	122,500
1998	3,000	72,700	2,800	55,600	5,700	128,300
1999	3,300	76,000	2,800	58,400	6,100	134,400
2000	3,200	79,200	2,800	61,200	6,000	140,400
2001	3,600	82,800	2,700	63,900	6,300	146,700
2002	2,900	85,700	2,800	66,700	5,700	152,400
2003	3,600	89,300	2,700	69,500	6,400	158,800
2004	3,100	92,400	2,700	72,200	5,800	164,600
2005	3,000	95,400	3,100	75,300	6,100	170,700
2006	3,300	98,700	2,600	77,900	5,900	176,600
2007	2,900	101,600	3,100	81,000	6,000	182,600
2008	3,800	105,300	2,600	83,500	6,300	188,900
2009	4,600	109,900	2,700	86,200	7,300	196,200
2010	3,800	113,700	2,900	89,200	6,700	202,900
2011	5,100	118,800	3,000	92,100	8,100	211,000
2012	3,300	122,100	2,700	94,900	6,100	217,000
2013	4,200	126,300	3,900	98,800	8,100	225,100
2014	5,100	131,400	2,900	101,700	8,000	233,100
2015	2,000	133,400	2,300	104,000	4,300	237,500
2016	2,500	135,900	3,000	107,000	5,500	242,900
2017	1,700	137,600	2,000	109,100	3,800	246,700
2018	1,900	139,600	1,800	110,800	3,700	250,400
2019	1,400	141,000	1,600	112,400	3,000	253,400
2020	1,600	142,600	2,100	114,500	3,700	257,100

[a]Ref. 1. Based on 104 GW(e) installed in the year 2000 and 54 GW(e) installed in the year 2020. Number of projected fuel assemblies reported has been rounded to the nearest 100.

[b]Reported historical data.

Table 1.6. Projected number of permanently discharged LWR spent fuel assemblies for the DOE/EIA Lower Reference Case[a]

End of calendar year	BWR		PWR		Total	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1989[b]	4,101	41,673	2,869	28,336	6,970	70,009
1990	3,500	45,200	3,600	32,000	7,200	77,200
1991	3,000	48,200	2,400	34,400	5,400	82,600
1992	4,100	52,400	3,700	38,100	7,800	90,500
1993	3,100	55,500	2,600	40,600	5,700	96,100
1994	3,500	59,000	3,300	44,000	6,900	103,000
1995	3,800	62,800	3,100	47,000	6,800	109,800
1996	3,500	66,200	2,700	49,800	6,200	116,000
1997	3,500	69,700	3,000	52,800	6,500	122,500
1998	3,000	72,700	2,800	55,600	5,700	128,300
1999	3,300	76,000	2,800	58,400	6,100	134,400
2000	3,200	79,200	2,800	61,200	6,000	140,400
2001	3,600	82,800	2,700	63,900	6,300	146,700
2002	2,900	85,700	2,800	66,700	5,700	152,400
2003	3,600	89,300	2,800	69,500	6,400	158,900
2004	3,100	92,400	2,800	72,400	5,900	164,800
2005	3,000	95,400	3,100	75,400	6,100	170,800
2006	3,300	98,700	2,700	78,100	6,000	176,800
2007	2,900	101,600	3,100	81,200	6,000	182,800
2008	3,800	105,300	2,600	83,800	6,400	189,200
2009	4,600	109,900	2,800	86,600	7,400	196,600
2010	4,000	113,900	2,900	89,600	6,900	203,500
2011	5,400	119,300	3,100	92,700	8,500	212,000
2012	3,300	122,600	2,800	95,500	6,100	218,100
2013	4,400	127,100	4,300	99,800	8,800	226,900
2014	5,100	132,200	4,200	104,000	9,300	236,100
2015	2,300	134,500	3,100	107,000	5,400	241,500
2016	2,900	137,300	4,200	111,200	7,000	248,500
2017	1,600	138,900	3,600	114,800	5,200	253,700
2018	1,900	140,800	3,800	118,500	5,700	259,400
2019	2,000	142,800	3,400	121,900	5,300	264,700
2020	1,400	144,200	4,400	126,200	5,700	270,400

[a]Ref. 1. Based on 104 GW(e) installed in the year 2000 and 116 GW(e) installed in the year 2020. Number of projected fuel assemblies reported has been rounded to the nearest 100.

[b]Reported historical data.

Table 1.7. Historical and projected spent fuel discharged from the Fort St. Vrain HTGR[a]

End of calendar year	Number of fuel assemblies discharged		Mass of fuel discharged (MTIHM)	
	Annual	Cumulative	Annual	Cumulative
1979	246[b]	246	2.80	2.80
1980	0	246	0.00	2.80
1981	240	486	2.77	5.57
1982	0	486	0.00	5.57
1983	0	486	0.00	5.57
1984	240	726	2.85	8.42
1985	0	726	0.00	8.42
1986	0	726	0.00	8.42
1987	0	726	0.00	8.42
1988	0	726[c]	0.00	8.42
1989	126[d]	852	1.32	9.74
1990	615[d,e]	1,467	6.47	16.21
1991[d]	741	2,208	7.79	24.00

[a]Based on ref. 8.
[b]This refueling replaced 246 spent fuel elements made up of 240 standard fuel elements and 6 fuel test elements.
[c]All spent fuel discharged prior to December 31, 1989, is located at the ICPP (see Table C.6 of Appendix C).
[d]Fuel removed from the core in 1989 and 1990 remains on-site in temporary storage wells until shipment to the ICPP can be accomplished or an independent spent fuel storage installation is built for permanent storage.
[e]1990: 330 fuel blocks have been removed from the core prior to February 28, 1990.

Table 1.8. IDB reference characteristics of LWR fuel assemblies

Characteristics	BWR[a]	PWR[b]
Overall assembly length, m	4.470	4.059
Cross section, cm	13.9 × 13.9	21.4 × 21.4
Fuel rod length, m	4.064	3.851
Active fuel height, m	3.759	3.658
Fuel rod outer diameter, cm	1.252	0.950
Fuel rod array	8 × 8	17 × 17
Fuel rods per assembly	63	264
Assembly total weight, kg	319.9	657.9
Uranium/assembly, kg	183.3	461.4
UO_2/assembly, kg	208.0	523.4
Zircaloy/assembly, kg	103.3[c]	108.4[d]
Hardware/assembly, kg	8.6[e]	26.1[f]
Total metal/assembly, kg	111.9	134.5
Nominal volume/assembly, m^3	0.0864[g]	0.186[g]

[a]Ref. 9.
[b]Ref. 10.
[c]Includes Zircaloy fuel-rod spacers and fuel channel.
[d]Includes Zircaloy control-rod guide thimbles.
[e]Includes stainless steel tie-plates, Inconel springs, and plenum springs.
[f]Includes stainless steel nozzles and Inconel-718 grids.
[g]Based on overall outside dimension. Includes spacing between the stacked fuel rods of an assembly.

Table 1.9. Historical mass of commercial BWR spent fuel discharged at various ranges of burnup[a,b]

End of calendar year	Annual mass of discharged spent fuel for various burnup ranges, MTIHM									Total annual mass over all burnup ranges (MTIHM)
	0-5,000[c]	5,001-10,000	10,001-15,000	15,001-20,000	20,001-25,000	25,001-30,000	30,001-35,000	35,001-40,000	40,001-45,000	
1968	0.6									0.6
1969		1.2	1.0	7.3	0.2					9.7
1970	5.6									5.6
1971	41.5	8.1	2.8	10.0	1.6					64.0
1972	97.9	12.1	27.6	4.0						141.5
1973	9.5	16.7	31.0	36.4	1.5	0.1				95.2
1974		78.4	117.7	44.7	3.8					244.6
1975	0.3	1.7	62.0	125.6	25.3					214.8
1976	0.9	62.0	105.6	127.7	2.3					298.5
1977		48.0	40.3	235.0	58.9	0.7				382.9
1978	6.3	32.4	13.1	84.2	232.0	15.2				383.2
1979			18.6	108.7	149.2	123.1	0.3			399.8
1980	14.0	0.4	0.6	93.3	413.3	87.6	10.7			619.9
1981		0.2	0.2	58.1	265.4	133.3	0.7	0.7		458.7
1982		0.2	4.6	19.4	144.7	173.6	13.8	0.6	0.4	357.2
1983			0.9	2.9	113.5	337.8	35.7	0.4		491.3
1984		5.4	9.5	0.4	136.2	239.5	70.8		0.4	462.2
1985	16.9	42.5	18.3	35.8	77.3	283.9	10.2		0.2	485.2
1986	50.8	38.2	42.5	72.8	62.6	159.4	37.3	0.4		464.0
1987	136.1	36.4	73.2	40.8	108.8	303.1	8.0		0.4	706.8
1988	17.0	24.6	2.4	43.9	176.1	237.4	35.0			536.5
1989	47.8	20.6	97.1	89.0	203.6	214.3	74.4	0.7		747.5

[a]Based on ref. 1.
[b]Does not include commercial spent fuel reprocessed at WVDP.
[c]Burnup range is given in units of MWd/MTIHM.

Table 1.10. Historical mass of commercial PWR spent fuel discharged at various ranges of burnup[a,b]

End of calendar year	Annual mass of discharged spent fuel for various burnup ranges, MTIHM												Total annual mass over all burnup ranges (MTIHM)
	0-5,000[c]	5,001-10,000	10,001-15,000	15,001-20,000	20,001-25,000	25,001-30,000	30,001-35,000	35,001-40,000	40,001-45,000	45,001-50,000	50,001-55,000	55,001-60,000	
1970			1.7	37.3									39.0
1971		4.6			2.5	19.4							26.5
1972			11.9	29.3	31.5	23.2	22.1						117.9
1973				26.2		33.3	7.6						67.1
1974	7.4	1.5	86.4	13.6	40.5	57.2	1.1						207.7
1975	2.7	42.6	95.0	48.2	84.8	25.3	23.1						321.8
1976			4.6	190.8	82.4	63.3	55.4						396.6
1977			2.8	108.3	118.2	135.2	87.1	15.4					466.9
1978		1.9	47.9	90.3	37.2	339.7	121.9	61.2	0.4				700.4
1979			31.0	107.1	64.0	232.3	234.7	50.1	0.5				719.8
1980			0.4		72.7	238.3	282.4	26.3	2.0		0.9		623.1
1981			17.2	1.9	25.8	230.4	353.0	53.3	1.3				682.8
1982			1.8	81.1	81.4	57.8	297.5	117.4	2.7	0.4	0.4	0.9	641.4
1983		5.5	4.1	71.4	51.1	176.2	321.6	136.2	5.4		0.5		771.9
1984			53.7	45.2	53.1	205.9	378.8	103.9	4.1				844.7
1985				44.3	11.8	222.1	330.4	225.1	24.2	0.4			858.3
1986		0.4	27.1	132.5	14.2	190.6	341.3	273.8	35.0	1.3	1.3		1,017.4
1987			27.6	133.4	82.3	134.2	418.7	334.2	24.4				1,154.8
1988	0.5			109.6	28.3	139.7	401.8	392.9	84.8	2.1	0.4	2.0	1,162.0
1989		25.9	50.6	126.3	24.9	153.5	337.6	428.5	91.1	11.8		0.4	1,250.8

[a]Based on ref. 1.
[b]Does not include commercial spent fuel reprocessed at WVDP.
[c]Burnup range is given in units of MWd/MTIHM.

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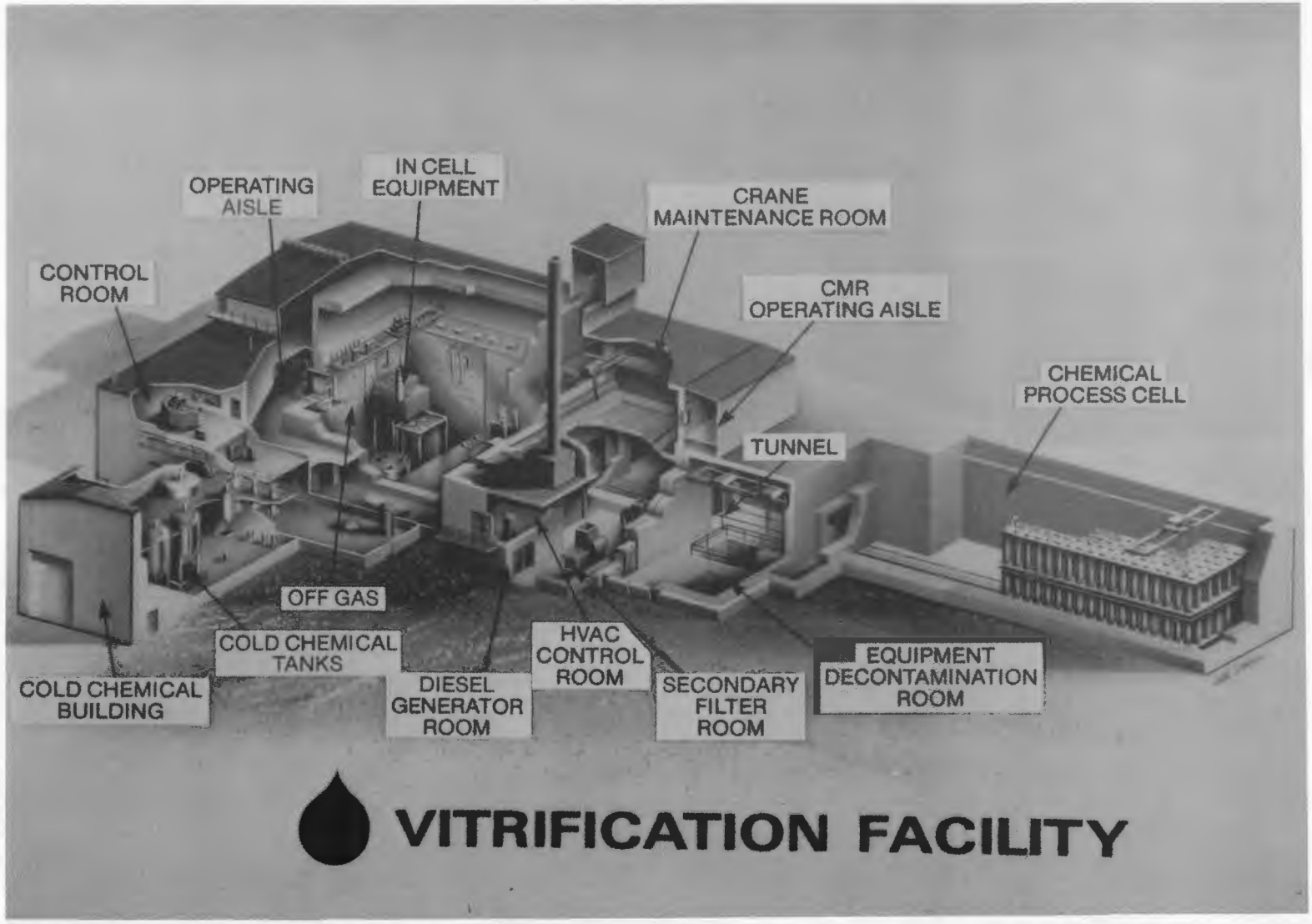

Photo 2.1. Artist's layout of the West Valley Vitrification Facility. (Courtesy of the West Valley Demonstration Project, West Valley, New York.)

2. HIGH-LEVEL WASTE

2.1 INTRODUCTION

High-level waste (HLW), which is generated by the reprocessing of spent reactor fuel and irradiated targets, generally contains more than 99% of the nonvolatile fission products produced in the fuel or targets during reactor operation. The HLW from a facility that recovers uranium and plutonium contains approximately 0.5% of these elements, while the HLW from a facility that recovers only uranium contains approximately 0.5% of the uranium and essentially all of the plutonium. Most of the present U.S. inventory of HLW is the result of DOE activities and is stored at the Savannah River Site (SRS), Idaho National Engineering Laboratory (INEL) [at the Idaho Chemical Processing Plant (ICPP)], and Hanford Site (HANF). A small amount of commercial HLW was generated at the Nuclear Fuel Services (NFS) Plant near West Valley, New York, during 1966-1972. That facility (located on land leased from the state of New York) is now referred to as the West Valley Demonstration Project (WVDP) and is the responsibility of the DOE Idaho Operations, West Valley Project Office. West Valley Nuclear Services, Inc. (a subsidiary of Westinghouse Electric Corporation), is the prime contractor and site operator. The prime contractor and site operator for HLW at SRS is Westinghouse Savannah River Company; for INEL (the ICPP) is Westinghouse Idaho Nuclear Company, Inc.; and for HANF is Westinghouse Hanford Company (all subsidiaries of Westinghouse Electric Corporation). The historical/projected HLW inventories presented here (except for HLW solidified in glass or ceramic forms) are for wastes in interim storage. These wastes have already undergone one or more treatment steps (e.g., neutralization, precipitation, decantation, or evaporation) and are not as generated. Their volumes depend strongly on the steps to which they are subjected. Most of these wastes will require incorporation into a stable, solid medium (e.g., glass) for final disposal. Data on the volume, radioactivity, distribution, and location of HLW (through 1989) are shown in Figs. 2.1-2.4. Present (and projected) HLW operations at these sites are depicted in Figs. 2.5-2.8.

The DOE HLW at INEL (Fig. 2.6), which is stored at the ICPP, results from the reprocessing of nuclear fuels from naval propulsion reactors and special research and test reactors. The acidic liquid portion of this waste is stored in tanks, although the bulk of this material has been converted to a stable, granular solid (calcine).

At SRS (Fig. 2.5) and HANF (Fig. 2.7), the acidic liquid waste from reprocessing production reactor fuel has been made alkaline with caustic soda and stored in tanks. During storage, these alkaline wastes separate into three phases: liquid, sludge, and salt cake. The relative proportions of liquid and salt cake depend upon how much water is removed by waste evaporators during interim waste management operations. The condensed water at HANF is sent to seepage basins. At SRS (Fig. 2.5), the condensate is sent to the Effluent Treatment Facility where it is treated and discharged to the environment. Also at SRS (Fig. A.10 in Appendix A), the processing of salt cake for future glassmaking generates a waste called precipitate. At HANF, all the wastes contained in double-shell tanks consists of mixtures of several wastes (Fig. 2.7), which have unique rheological properties and are referred to as slurry. A determination that all the wastes contained in double-shell tanks are HLW has not been made; however, they are managed as such.

The commercial HLW at WVDP consists of both alkaline and acidic wastes (Fig. 2.8); the alkaline waste was generated by reprocessing of commercial power reactor fuels and Hanford N-Reactor fuels, while the acidic waste was generated by reprocessing a small amount of commercial fuel containing thorium. Also at WVDP, the processing of liquid waste for future glassmaking generates a granular solid waste which is a zeolite loaded with radioactive cesium (Fig. 2.8).

The historical and projected inventories of HLW that is stored in tanks, bins, and capsules are presented in Table 2.1. Projected inventories of HLW that is incorporated into glass are given in Table 2.2. A year-by-year estimate of the number of HLW canisters, by source, is presented in Table 2.3. The 1988 estimate of DOE HLW canister totals, as required for repository disposal costs, is presented in Table 2.4. The inventories of HLW that is in storage at the end of 1989 are listed in Table 2.5 (volume) and Table 2.6 (radioactivity). Historical and projected volume, radioactivity, and thermal power data for DOE and commercial HLW are given in Tables 2.7-2.9. The data for DOE sites represent a summary of information obtained from each of the

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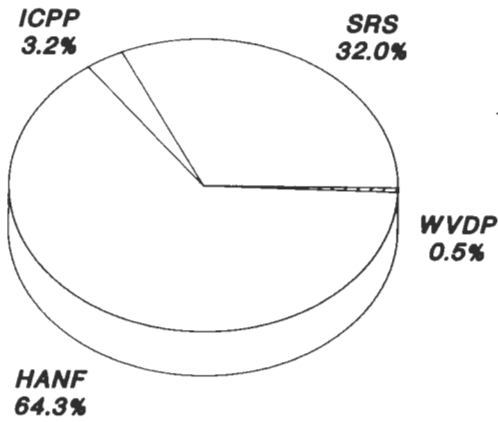

SITE	CUBIC METERS
SRS	1.22E+05
ICPP	1.20E+04
HANF	2.45E+05
WVDP	1.88E+03
TOTAL	3.81E+05

COMMERCIAL

DOE

Fig. 2.1. Total volume of HLW through 1989.

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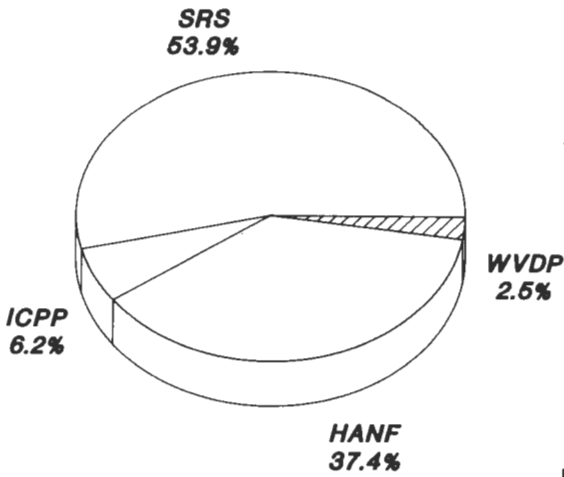

SITE	CURIES
SRS	5.99E+08
ICPP	6.84E+07
HANF	4.16E+08
WVDP	2.79E+07
TOTAL	1.11E+09

COMMERCIAL

DOE

Fig. 2.2. Total radioactivity of HLW through 1989.

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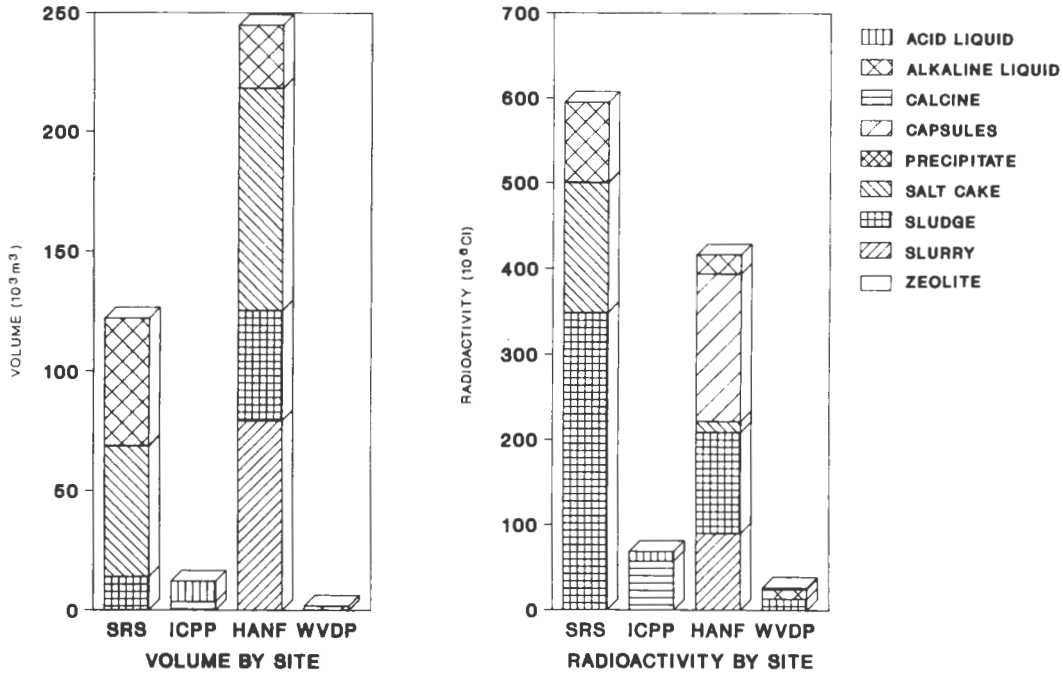

Fig. 2.3. Distribution of total accumulative volume and radioactivity of HLW by site and type through 1989.

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Fig. 2.4. Locations and total volumes of HLW through 1989.

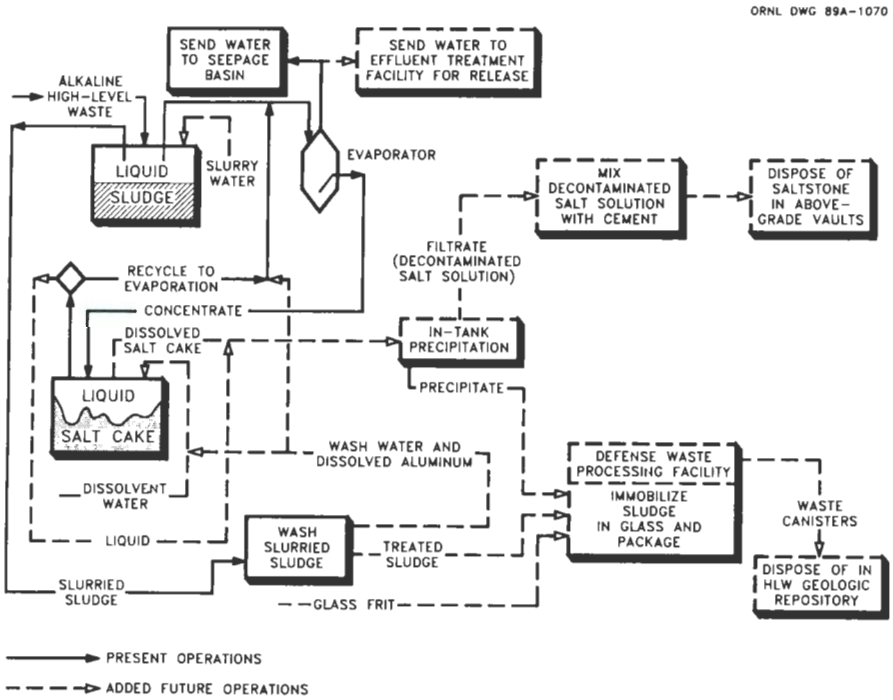

Fig. 2.5. Treatment methods for HLW in tanks and canisters at SRS.

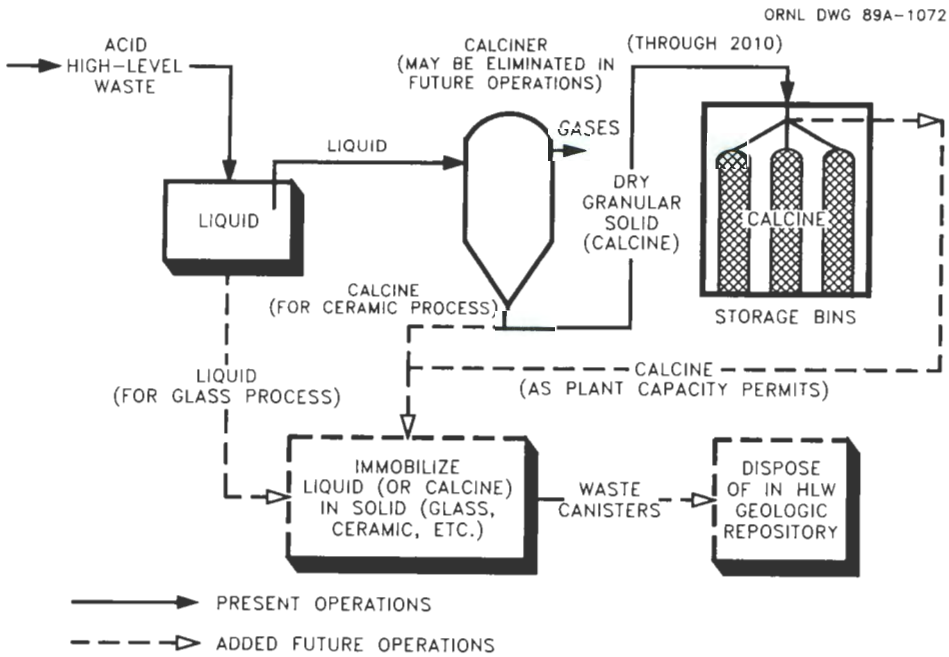

Fig. 2.6. Treatment methods for HLW in tanks, bins, and canisters at INEL.

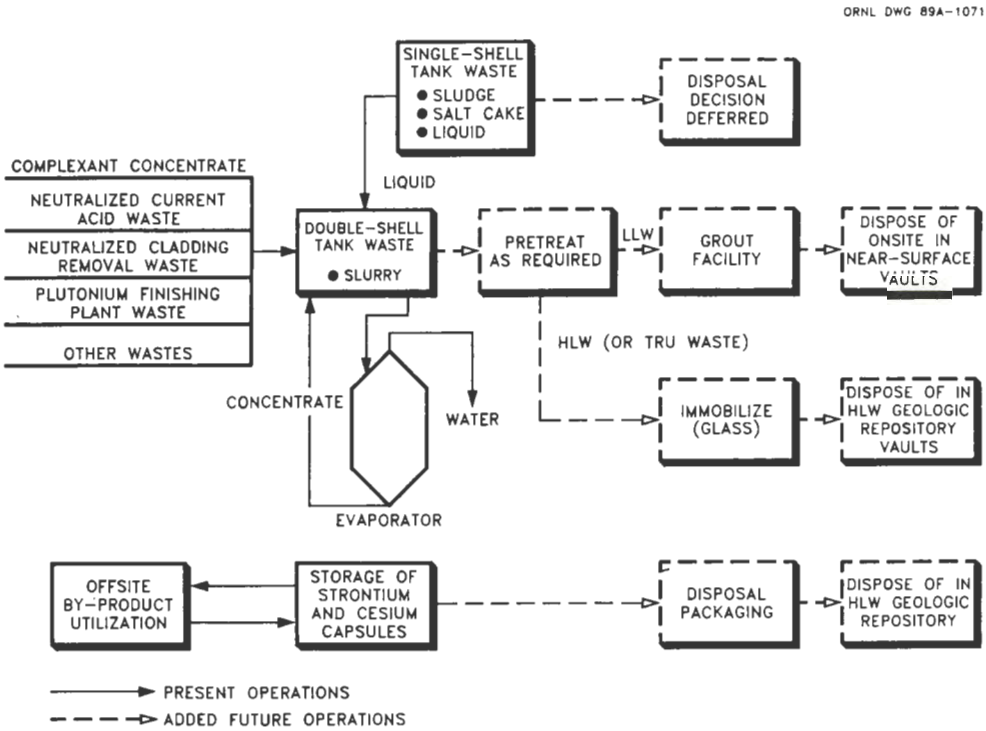

Fig. 2.7. Treatment methods for HLW in tanks, capsules, and canisters at HANF.

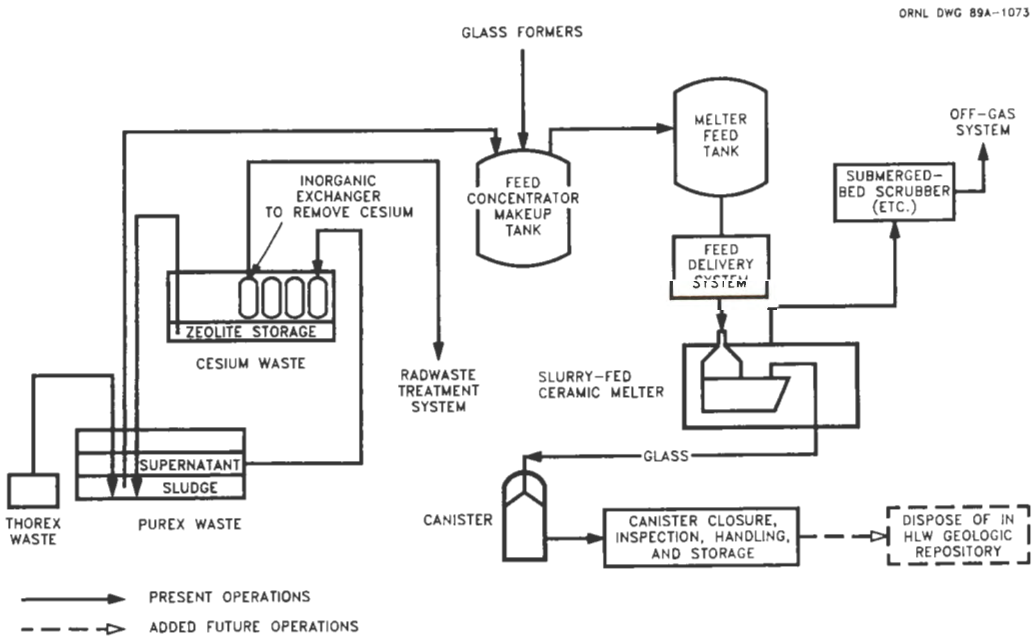

Fig. 2.8. Treatment methods for HLW in tanks and canisters at WVDP.

sites.[1-3] The information on commercial HLW at WVDP was taken from data given in ref. 4.

2.2 INVENTORIES

Inventories of HLW at the various DOE sites and the WVDP through 1989 are presented in this section. Significant changes affecting HLW inventories are shown in Table 2.10.

2.2.1 HLW Inventories at SRS (DOE)

Approximately 122,000 m^3 of alkaline HLW that has accumulated at the SRS during the past three to four decades is being stored in underground, high-integrity, double-walled, carbon-steel tanks. The current inventories (Tables 2.5 and 2.6) include alkaline liquid (53,300 m^3), sludge (13,800 m^3), salt cake (54,800 m^3), and precipitate (125 m^3) that were generated primarily by the PUREX reprocessing of nuclear fuels and targets from production reactors. Most of the waste, as generated, is acidic liquid, and the sludge is formed during subsequent treatment with caustic and during aging. Salt cake results when the supernatant liquor is concentrated in evaporators. Precipitate results when salt cake is treated by the in-tank precipitation process.

2.2.2 HLW Inventories at INEL (DOE)

The 12,000 m^3 of HLW stored at INEL (at the ICPP) consists of 8,500 m^3 of liquid waste and 3,500 m^3 of calcine (Tables 2.5 and 2.6). Liquid HLW is generated at ICPP primarily by the reprocessing of spent fuel from naval propulsion nuclear reactors and reactor testing programs; a small amount is generated by reprocessing fuel from research reactors. This acidic liquid waste is stored in underground stainless steel tanks that are housed in concrete vaults. The waste is then converted to a calcine and stored retrievably in stainless steel bins that are housed in reinforced concrete vaults.

2.2.3 HLW Inventories at HANF (DOE)

The 244,800 m^3 of alkaline HLW stored at HANF is categorized as liquid (26,500 m^3), sludge (46,000 m^3), and salt cake (93,000 m^3) that are stored in single-shell tanks and as slurry (79,300 m^3) that is stored in double-shell tanks. This waste, which has been accumulating since 1944, was generated by the reprocessing of production reactor fuel for the recovery of plutonium, uranium, and neptunium for defense and other national programs. This reprocessing was suspended from 1972 until November 1983. Most of the high-heat-emitting isotopes (^{90}Sr and ^{137}Cs, plus their daughters) were removed from the old waste, converted to solids (strontium fluoride and cesium chloride), placed in double-walled capsules, and stored in a water basin. At present, 1,350 cesium capsules (2.49 m^3) and 597 strontium capsules (1.06 m^3) are stored in the basin. The liquid, sludge, salt-cake, and slurry wastes are stored in underground concrete tanks with carbon-steel liners. Current inventories of these wastes at HANF are listed in Tables 2.5 and 2.6.

2.2.4 HLW Inventories at WVDP (Commercial)

Reprocessing at the NFS plant was terminated in 1972, and no additional HLW has been generated since that time. As of December 31, 1989, the 1,877 m^3 of HLW stored at WVDP consists of 1,796 m^3 of alkaline waste (1,750 m^3 of liquid plus 46 m^3 of sludge), 50 m^3 of acidic waste, and 31 m^3 of an inorganic ion-exchange material (a zeolite) loaded with radioactive cesium (^{134}Cs, ^{135}Cs, and ^{137}Cs). The alkaline waste was generated by reprocessing commercial and Hanford N-Reactor spent fuels. As generated, the waste was acidic; treatment with excess sodium hydroxide resulted in the formation of an alkaline sludge. The small amount of acidic waste now in storage was generated by reprocessing a batch of thorium-uranium fuel from the Indian Point-1 Reactor. Storage for the alkaline waste is in an underground carbon-steel tank, while the acidic waste is stored in an underground stainless-steel tank.

In May 1988, the processing of high-level alkaline liquid waste started at the WVDP. This alkaline liquid is being decontaminated to LLW in the WVDP Supernatant Treatment System (STS) in preparation for the incorporation of all HLW at the WVDP into a glass. In the STS, a batch process which utilizes ion exchange is employed to remove cesium from liquid waste (supernatant), as depicted in Fig. 2.8. The ion-exchange columns are located in the underground carbon-steel tank originally installed as a backup tank for alkaline HLW. When the supernatant has been processed, the sludge in the bottom of the tank will be washed. The washed sludge, acidic waste, and loaded zeolite will be combined and incorporated into a glass. The current inventories of HLW at WVDP are presented in Tables 2.5 and 2.6.

2.3 WASTE CHARACTERIZATION

A generic characterization of HLW at any site is difficult, since over the years several different flowsheets have been used for the processes that generated the wastes and several methods have been employed to prepare the wastes for storage (e.g., evaporation and precipitation). In some instances, various types of wastes have been blended. However, representative data on chemical and radionuclide compositions are given in Tables 2.11–2.20 for current and projected HLW at SRS, ICPP, HANF, and WVDP. The information used to construct these tables was taken from refs. 1–4, as well as from the references cited in the footnotes to the tables.

2.4 PROJECTIONS

Projected inventories (volume, radioactivity, and thermal power) for HLW are presented in Tables 2.7–2.9.

The HLW projections for SRS are based on the assumption that (1) three reactors will be restarted during 1990–1991 and will be operating through September of 2004; (2) these three reactors will be replaced by a single new production reactor which will begin operation in late 2000; and (3) the Defense Waste Processing Facility (DWPF) will begin to produce a glass waste form (see flowsheet in Fig. A.10 of Appendix A) in March 1992, following the schedule shown in Table 2.3. The HLW glass will be stored on-site until a national repository[5-7] becomes available. Current plans call for the DWPF to produce 5,282 canisters of glass between 1992 and the end of 2020.

The HLW projections for ICPP are based on predictions of fuel delivery and estimates of continued operation of fuel reprocessing and waste management through 2020. A facility to immobilize newly generated HLW at ICPP is planned for operation by the early part of the next century.[8] It will also be able to process the stored calcine. Evaluations of waste immobilization processes are continuing at ICPP, with the identification of a reference waste form (glass, ceramic, etc.) and process scheduled for completion in the 1990s. An estimate of a potential number of canisters is shown in Table 2.3. The projections of HLW presented in Tables 2.7–2.9 for ICPP are based on the waste composition prior to immobilization.

The HLW projections for HANF are based on continued operation of the fuel reprocessing plant through 1996. A Hanford Waste Vitrification Plant (HWVP) is to begin operation in 1999.[8-9] The planned operations for the HWVP are discussed in the Hanford Defense Waste Environmental Impact Statement.[10] Estimates of the number of canisters of HLW incorporated in borosilicate glass that might be generated annually by the HWVP are given in Table 2.3. The projections of HLW given in Tables 2.7–2.9 for HANF do not include vitrification, since material balances for such processes are not yet available.

The cost for the disposal of DOE HLW in a national repository will be paid by DOE into the Nuclear Waste Fund. Reference 11 states that the number of canisters used in the annual estimate of this cost will be published in the IDB. Consequently, projections of the potential total number of DOE HLW canisters from SRS, ICPP, and HANF are presented in Table 2.4. Table 2.3 includes potential production schedules for canisters, which are not used in the disposal cost estimate. Table 2.4 shows the possible number of canisters, which could be produced from various waste streams, separated into four categories. The projections, totaling 6,100 canisters, in the committed category are based on National Environmental Policy Act (NEPA)-supported commitments to geological disposal by DOE. The projections in the other three categories are not based on NEPA decisions and reflect differing levels of uncertainty in the information used to determine the values for the number of canisters.

The DOE has recently proposed a plan for two new production reactors (NPRs) to provide defense material into the next century. Several reactor concepts and sites were considered. Projections, based on current technology, have been made of the possible volume of HLW. A range of the possible number of canisters estimated for solidified NPR-HLW is shown in Table 2.4.

At the WVDP, vitrification of the HLW (Fig. 2.8) is scheduled to begin in late 1993 and to be completed in early 1995.

2.5 REFERENCES

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5. U.S. Congress, The Nuclear Waste Policy Act of 1982, Pub. L. 97-425, Sect. 8, Jan. 7, 1983, as amended.

6. Ronald Reagan, President of the United States, Washington, D.C., letter to John S. Herrington, Secretary of Energy, "Disposal of Defense Waste in a Commercial Repository," dated Apr. 30, 1985.

7. U.S. Congress, The Nuclear Waste Policy Amendments Act of 1987, Pub. L. 100-203, Title V, Subtitle A, Dec. 22, 1987.

8. U.S. Department of Energy, Office of Defense Waste and Transportation Management, Defense Waste and Transportation Management Program Implementation Plan, DOE/DP-0059, Washington, D.C. (August 1988).

9. Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Hanford Federal Facility Agreement and Consent Order, EPA Docket Number 1089-03-040120, Ecology Docket Number 89-54, Richland, Washington (May 1989).

10. U.S. Department of Energy, Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic, and Tank Waste, Hanford Site, Richland, Washington, DOE/EIS-0113, U.S. Department of Energy, Richland, Washington (December 1987).

11. U.S. Department of Energy, "Civilian Radioactive Waste Management: Calculating Nuclear Waste Fund Disposal Fees for Department of Energy Defense Program Waste; Notice," Fed. Regist. 56(161), 31508 (Aug. 20, 1987).

Table 2.1. Historical and projected total accumulative volume, radioactivity, and thermal power of HLW stored in tanks, bins, and capsules by source[a,b]

End of calendar year	Accumulation		
	Volume (10^3 m^3)	Radioactivity (10^6 Ci)	Thermal power (10^3 W)
	DOE/defense (SRS, ICPP, and HANF)		
1980	295	1,310	3,298
1981	305	1,577	4,748
1982	340	1,316	3,919
1983	351	1,248	3,653
1984	361	1,396	4,222
1985	355	1,465	4,467
1986	364	1,417	4,476
1987	379	1,277	3,750
1988	383	1,177	3,389
1989	379	1,084	3,080
1990	399	1,031	2,924
1991	383	1,025	2,944
1992	378	1,059	3,097
1993	379	1,060	3,098
1994	366	1,069	3,137
1995	362	1,029	3,009
1996	359	1,047	3,128
1997	356	1,018	3,031
1998	352	1,085	3,344
1999	350	1,016	3,093
2000	350	979	2,974
2001	345	1,048	3,295
2002	349	1,067	3,374
2003	347	1,071	3,393
2004	343	1,054	3,403
2005	342	1,066	3,382
2006	341	910	2,787
2007	343	827	2,507
2008	346	793	2,388
2009	347	777	2,334
2010	349	785	2,371
2011	350	790	2,391
2012	351	804	2,442
2013	351	812	2,460
2014	353	821	2,511
2015	355	826	2,499
2016	356	835	2,558
2017	356	833	2,569
2018	359	843	2,563
2019	356	829	2,497
2020	358	839	2,526
	Commercial (WVDP)		
1980	2.2	34.2	102.0
1981	2.2	33.4	99.6
1982	2.2	32.7	97.2
1983	2.2	31.9	95.0
1984	2.2	31.2	92.8
1985	2.2	30.4	90.5
1986	2.2	29.7	88.4
1987	2.2	29.2	85.5
1988	2.1	28.7	85.3
1989	1.9	27.9	83.2
1990	1.6	27.2	81.2
1991	1.4	26.6	79.3
1992	1.2	26.0	77.5
1993	1.0	21.2	63.0
1994	0.2	4.2	12.2

Table 2.1 (continued)

End of calendar year	Accumulation		
	Volume (10^3 m^3)	Radioactivity (10^6 Ci)	Thermal power (10^3 W)
		Total	
1980	297	1,344	3,400
1981	307	1,610	4,848
1982	342	1,349	4,016
1983	353	1,280	3,748
1984	363	1,427	4,315
1985	357	1,496	4,557
1986	366	1,447	4,565
1987	381	1,306	3,836
1988	385	1,206	3,474
1989	381	1,112	3,164
1990	400	1,058	3,005
1991	384	1,052	3,024
1992	379	1,085	3,175
1993	380	1,081	3,161
1994	366	1,074	3,150
1995	362	1,029	3,009
1996	359	1,047	3,128
1997	356	1,018	3,031
1998	352	1,085	3,344
1999	350	1,016	3,093
2000	350	979	2,974
2001	345	1,048	3,295
2002	349	1,067	3,374
2003	347	1,071	3,393
2004	343	1,054	3,403
2005	342	1,066	3,382
2006	341	910	2,787
2007	343	827	2,507
2008	346	793	2,451
2009	347	777	2,393
2010	349	785	2,406
2011	350	790	2,401
2012	351	804	2,446
2013	351	812	2,465
2014	353	821	2,523
2015	355	826	2,529
2016	356	835	2,593
2017	356	833	2,618
2018	359	843	2,620
2019	356	829	2,536
2020	358	839	2,548

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 5 (November 1989)]. The inventories for 1989 and the projections through 2020 are taken from refs. 1-4.

[b]Annual rates for volume are not given since they can fluctuate widely depending upon waste generation (or nongeneration) coupled with waste management operations such as evaporation and/or calcination. Annual rates for radioactivity and thermal power are not given for the same reasons plus the fact that radioactive decay, especially for short-lived activity, causes apparent perturbations.

Table 2.2. Projected volume, radioactivity, and thermal power of HLW glass stored in canisters by source[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^6 Ci)		Thermal power (10^3 W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			DOE/defense (SRS)[b]			
1992	0.09	0.09	23	23	57	57
1993	0.19	0.28	30	52	78	133
1994	0.23	0.51	37	88	95	223
1995	0.26	0.77	65	150	203	413
1996	0.26	1.03	65	211	209	603
1997	0.23	1.26	58	264	180	763
1998	0.24	1.50	54	311	169	908
1999	0.23	1.73	42	346	136	1,019
2000	0.21	1.94	35	372	112	1,104
2001	0.21	2.15	30	393	96	1,171
2002	0.22	2.37	27	411	86	1,227
2003	0.21	2.58	25	426	79	1,276
2004	0.19	2.77	23	438	74	1,318
2005	0.17	2.94	21	449	69	1,355
2006	0.17	3.11	20	459	65	1,387
2007	0.17	3.28	20	467	62	1,416
2008	0.02	3.30	4	460	12	1,397
2009		3.30		450		1,368
2010		3.30		440		1,340
2011		3.30		429		1,310
2012		3.30		419		1,282
2013		3.30		410		1,253
2014		3.30		400		1,226
2015		3.30		391		1,199
2016		3.30		382		1,172
2017		3.30		373		1,147
2018		3.30		365		1,122
2019		3.30		356		1,098
2020		3.30		348		1,074
			Commercial (WVDP)[c]			
1993	0.035	0.035	4.1	4.1	12.7	12.7
1994	0.140	0.175	16.5	20.5	49.9	61.6
1995	0.035	0.210	4.3	24.2	12.7	72.0
1996		0.210		23.6		70.4
1997		0.210		23.0		68.7
1998		0.210		22.5		67.2
1999		0.210		22.0		65.6
2000		0.210		21.5		64.2
2001		0.210		21.0		62.7
2002		0.210		20.5		61.2
2003		0.210		20.0		59.9
2004		0.210		19.5		58.6
2005		0.210		19.1		57.2
2006		0.210		18.6		55.9
2007		0.210		18.2		54.6
2008		0.210		17.8		53.5
2009		0.210		17.4		52.2
2010		0.210		17.0		51.0
2011		0.210		16.6		49.9
2012		0.210		16.2		48.8
2013		0.210		15.8		47.6
2014		0.210		15.5		46.6
2015		0.210		15.1		45.5
2016		0.210		14.8		44.4
2017		0.210		14.4		43.6
2018		0.210		14.1		42.6
2019		0.210		13.8		41.6
2020		0.210		13.4		40.6

Table 2.2 (continued)

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^6 Ci)		Thermal power (10^3 W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
			Total			
1992	0.090	0.090	22.0	23	53.0	57
1993	0.225	0.315	34.1	56	85.7	145
1994	0.370	0.685	53.5	108	138.9	285
1995	0.295	0.98	68.3	174	202.7	485
1996	0.26	1.24	64	235	196	673
1997	0.23	1.47	57	287	169	832
1998	0.24	1.71	53	333	158	975
1999	0.23	1.94	42	368	127	1,085
2000	0.21	2.15	35	394	105	1,168
2001	0.21	2.36	30	414	90	1,234
2002	0.22	2.58	27	431	81	1,288
2003	0.21	2.79	24	446	74	1,336
2004	0.19	2.98	23	458	69	1,377
2005	0.17	3.15	21	468	65	1,412
2006	0.17	3.32	20	477	61	1,443
2007	0.17	3.49	19	486	58	1,471
2008	0.02	3.51	4	478	11	1,451
2009		3.51		467		1,420
2010		3.51		457		1,391
2011		3.51		446		1,360
2012		3.51		436		1,331
2013		3.51		426		1,301
2014		3.51		416		1,273
2015		3.51		406		1,245
2016		3.51		397		1,216
2017		3.51		387		1,191
2018		3.51		379		1,165
2019		3.51		370		1,140
2020		3.51		361		1,115

[a]Glass may be in storage at the site, in transit to a repository, or in a repository.

[b]Taken from or calculated with data given in ref. 1. The DWPF (see Fig. A.10 in Appendix A) canisters are 2-ft-diam × 10-ft-long. Each is assumed to be filled with 0.637 m^3 of glass [i.e., 85% of the usable capacity (0.736 m^3)] made with HLW from the reprocessing of spent fuel at SRS. The glass incorporates 36 wt % oxides from waste (28 wt % from spent fuel and 8 wt % from processing chemicals) and 64 wt % oxides from nonradioactive glass frit. Volumes reported are for the glass waste form and not the canisters (see Table 2.3 for the number of canisters).

[c]Taken from data given in ref. 4. It is assumed that 300 canisters (2-ft-diam × 10-ft-long) are filled with waste glass during 1993–1995 and that each canister contains 0.7 m^3 of glass at the filling temperature.

Table 2.3. Estimated potential number of HLW canisters by source[a]

	Number of canisters[b]							
	SRS[c]		ICPP[d]		HANF[e]		WVDP[f]	
Year	Annual	Accumulation	Annual	Accumulation	Annual	Accumulation	Annual	Accumulation
1992	136	136	–	–	–	–	–	–
1993	308	444	–	–	–	–	50	50
1994	376	820	–	–	–	–	200	250
1995	410	1,230	–	–	–	–	50	300
1996	410	1,640	–	–	–	–	–	300
1997	383	2,023	–	–	–	–	–	300
1998	369	2,392	–	–	–	–	–	300
1999	369	2,761	–	–	–	–	–	300
2000	342	3,103	–	–	240	240	–	300
2001	342	3,445	–	–	370	610	–	300
2002	342	3,787	–	–	345	955	–	300
2003	342	4,129	–	–	185	1,140	–	300
2004	302	4,431	–	–	370	1,510	–	300
2005	273	4,704	–	–	370	1,880	–	300
2006	273	4,977	–	–	144	2,024	–	300
2007	273	5,250	–	–	64	2,088	–	300
2008	32	5,282	–	–	64	2,152	–	300
2009	–	5,282	–	–	64	2,216	–	300
2010	–	5,282	–	–	64	2,280	–	300
2011	–	5,282	–	–	–	2,280	–	300
2012	–	5,282	500	500	–	2,280	–	300
2013	–	5,282	600	1,100	–	2,280	–	300
2014	–	5,282	700	1,800	–	2,280	–	300
2015	–	5,282	1,000	2,800	–	2,280	–	300
2016	–	5,282	1,000	3,800	–	2,280	–	300
2017	–	5,282	1,000	4,800	–	2,280	–	300
2018	–	5,282	1,000	5,800	–	2,280	–	300
2019	–	5,282	1,000	6,800	–	2,280	–	300
2020	–	5,282	1,000	7,800	–	2,280	–	300

[a]Taken from refs. 1–4. The projected waste volumes, radioactivity, and thermal power values at SRS and WVDP are consistent with the number of canisters reported since these sites are further along in their solidification programs and have developed definitive and defensible material balances for their solidification facilities. The number of canisters at ICPP and HANF are estimates since the solidification facilities at these sites are still in the planning stage.

[b]Canisters are 2-ft diam × 10-ft length.

[c]Each canister is assumed to contain 0.637 m^3 of glass made with HLW from the reprocessing of spent fuel at SRS. The glass incorporates 36 wt % oxides from waste (28 wt % from spent fuel and 8 wt % from processing chemicals) and 64 wt % oxides from nonradioactive glass frit.

[d]Each canister is assumed to contain 0.57 m^3 of a ceramic waste form incorporating 70 wt % solids from waste.

[e]Each canister of vitrified waste is assumed to contain 0.62 m^3 of a borosilicate glass incorporating waste solids. The glass in 1,460 of these canisters includes solids from neutralized current acid waste and complexant concentrate. In addition to the canisters of glass, 320 canisters (overpacks) containing strontium capsules and cesium capsules, as well as 500 canisters from neutralized cladding removal waste and plutonium finishing plant waste, are projected to be produced. The 500 latter canisters meet the definition of TRU waste and are candidates for disposal at the Waste Isolation Pilot Plant.

[f]Each canister is assumed to contain 0.7 m^3 of a borosilicate glass incorporating waste solids.

Table 2.4. The 1988 estimate of the number of defense HLW canisters that could be produced from stored and projected HLW[a]

Interim waste form/ source and generation/ generation period	Estimated number of canisters (Values rounded to nearest 100)			
	Committed to disposal[b]	High potential for disposal[c]	Medium potential for disposal[d]	Not included[e]
		Savannah River Site[f]		
Tank waste (liquid, salt cake, and sludge)				
Start-1987	4,600			
1988-2000	1,000			
		Idaho Chemical Processing Plant[g]		
Calcined waste				
Start-1987		3,800		
1988-2020		16,300		
2021-2033			9,500	
		Hanford Site[h]		
Double-shell tanks				
Slurry				
NCAW[i]	500			
CC-1987[j]		200-600		
CC after 1987[k]			0-400	
PFP[l]				100
NCRW[m]				400
Cs and Sr capsules[n]		300		
Single-shell tanks[o] (liquid, salt cake, and sludge)			0-24,000	
		Undesignated site		
New production reactor[p] (2000-2040)		800-1,000		
Total	6,100	21,400-22,000	9,500-33,900	500

[a]Taken from ref. 3 in the previous edition of this report [i.e., DOE/RW-0006, Rev. 5 (November 1989)]. Data required for repository program planning.

[b]Committed values are well established (e.g., DWPF glass) and are based on National Environmental Policy Act (NEPA) decisions.

[c]High-potential values are not supported by a NEPA action and/or are less sharply known.

[d]Medium-potential values are not supported by a NEPA action and/or they are based on imprecise source estimates or undeveloped treatment technology.

[e]Projections are not included when values are very imprecisely known or the waste is non-HLW that has been associated with past canister estimates. Values are for reference only.

[f]Canisters from the DWPF contain glass made with existing HLW and HLW from the operation of existing reactors through 2000.

[g]Canisters contain a ceramic waste form made with HLW from the reprocessing of naval nuclear propulsion fuels. Estimated projections beyond 2020 are less precise. Projected values assume no on-site disposal of calcine and no removal of inerts from the original waste streams.

[h]Slurry refers to all waste in double-shell tanks regardless of when it was generated.

[i]Neutralized current acid waste (NCAW) is HLW from existing N-Reactor fuel.

[j]Complexant concentrate (CC) generated through 1987 will be vitrified but the volume is not precisely known.

[k]Complexant concentrate (CC) source beyond 1987 is not clearly defined.

[l]Plutonium Finishing Plant (PFP) waste is not HLW by source definition.

[m]Neutralized coating removal waste (NCRW) is not HLW by source definition.

[n]Capsule waste has been designated for repository disposal (ref. 7) but the final form has not been determined.

[o]Single-shell tank waste has not been designated through NEPA to be sent to a repository. Final class and recommended treatment are still being studied.

[p]HLW from new production reactors will probably be sent to a repository, but no NEPA action has been initiated. The expected volume is relatively firm.

Table 2.5. Current volume of HLW in storage by site through 1989

Site[a]	Volume, 10^3 m^3									
								Capsules[d]		
	Liquid	Sludge	Salt cake	Slurry[b]	Calcine	Precipitate[c]	Zeolite	Sr	Cs	Total
Defense[e]										
SRS	53.3	13.8	54.8	f	f	0.125	f	f	f	122.0
ICPP	8.5	f	f	f	3.5	f	f	f	f	12.0
HANF[g]	26.5	46.0	93.0	79.3	f	f	f	0.00106	0.00249	244.8
Subtotal	88.3	59.8	147.8	79.3	3.5	0.125	f	0.00106	0.00249	378.8
Commercial[h]										
WVDP										
Acid waste	0.05	f	f	f	f	f	f	f	f	0.050
Alkaline waste	1.75	0.046	f	f	f	f	f	f	f	1.796
Zeolite waste	f	f	f	f	f	f	0.031	f	f	0.031
Subtotal	1.80	0.046	f	f	f	f	0.031	f	f	1.877
Total	90.1	59.85	147.8	79.3	3.5	0.125	0.031	0.00106	0.00249	380.7

[a]SRS is Savannah River Site, ICPP is Idaho Chemical Processing Plant, HANF is Hanford Site, and WVDP is West Valley Demonstration Project.

[b]Slurry refers to all waste (regardless of when it was generated) contained in double-shell tanks.

[c]Precipitate (non-Newtonian fluid) from the in-tank precipitation process.

[d]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[e]Taken from refs. 1-3.

[f]Not applicable.

[g]A determination has not been made that single-shell tank wastes (i.e., liquid, sludge, and salt cake) at HANF are high-level wastes, although these wastes are managed as such at the site.

[h]Taken from ref. 4.

Table 2.6. Current radioactivity of HLW in storage by site through 1989

Site[b]	Radioactivity,[a] 10^6 Ci										Thermal power (10^6 W)
	Liquid	Sludge	Salt cake	Slurry[c]	Calcine	Precipitate[d]	Zeolite	Capsules[e] Sr	Capsules[e] Cs	Total	
Defense[f]											
SRS	94.6	351.2	152.8	g	g	0.31	g	g	g	598.9	1.674
ICPP	11.5	g	g	g	56.9	g	g	g	g	68.4	0.199
HANF[h]	22.6	118.5	12.3	89.8	g	g	g	54.5	118.7	416.4	1.208
Subtotal	128.7	469.7	165.1	89.8	56.9	0.31	g	54.5	118.7	1,083.7	3.081
Commercial[i]											
WVDP											
Acid waste	1.7	g	g	g	g	g	g	g	g	1.7	0.005
Alkaline waste	11.3	13.0	g	g	g	g	g	g	g	24.3	0.074
Zeolite waste	g	g	g	g	g	g	1.9	g	g	1.9	0.004
Subtotal	13.0	13.0	g	g	g	g	1.9	g	g	27.9	0.083
Total	141.7	482.7	165.1	89.8	56.9	0.31	1.9	54.5	118.7	1,111.6	3.164

[a]Calculated values allowing for radioactive decay.

[b]SRS is Savannah River Site, ICPP is Idaho Chemical Processing Plant, HANF is Hanford Site, and WVDP is West Valley Demonstration Project.

[c]Slurry refers to all waste (regardless of when it was generated) contained in double-shell tanks.

[d]Precipitate (non-Newtonian fluid) from the in-tank precipitation process.

[e]Capsules contain either strontium (^{90}Sr–^{90}Y) fluoride or cesium (^{137}Cs–^{137m}Ba) chloride. Radioactivity values are for the pair, that is, parent plus daughter radionuclide.

[f]Taken from refs. 1–3.

[g]Not applicable.

[h]A determination has not been made that single-shell tank wastes (i.e., liquid, sludge, and salt cake) at HANF are high-level wastes, although these wastes are managed as such at the site.

[i]Taken from ref. 4.

Table 2.7. Historical and projected total accumulative volume of HLW in storage by site through 2020[a]

End of calendar year	Volume, 10^3 m^3									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Savannah River Site					
1980	59.8	10.5	26.4	-	-	-	-	-	-	97
1981	66.3	11.8	27.6	-	-	-	-	-	-	106
1982	72.9	12.3	29.8	-	-	-	-	-	-	115
1983	65.9	12.8	32.7	-	-	-	-	-	-	111
1984	77.8	13.8	34.0	-	-	-	-	-	-	126
1985	71.3	13.8	37.6	-	-	-	-	-	-	123
1986	72.8	13.8	41.2	-	-	-	-	-	-	128
1987	63.2	13.8	50.5	-	-	0.1	-	-	-	128
1988	64.2	14.1	50.0	-	-	0.1	-	-	-	128
1989	53.3	13.8	54.8	-	-	0.1	-	-	-	122
1990	59.1	14.8	54.2	-	-	0.3	-	-	-	128
1995	46.9	14.9	41.3	-	-	1.6	-	-	0.8	105
2000	43.6	10.3	24.7	-	-	0.8	-	-	1.9	81
2005	41.2	8.3	14.8	-	-	0.2	-	-	2.9	67
2010	42.8	9.0	19.7	-	-	-	-	-	3.3	75
2015	42.2	9.7	21.4	-	-	0.5	-	-	3.3	77
2020	42.9	10.4	21.4	-	-	1.1	-	-	3.3	79
					Idaho Chemical Processing Plant					
1980	9.3	-	-	-	2.1	-	-	-	-	11
1981	9.8	-	-	-	2.2	-	-	-	-	12
1982	9.1	-	-	-	2.4	-	-	-	-	12
1983	6.9	-	-	-	2.8	-	-	-	-	10
1984	7.1	-	-	-	3.0	-	-	-	-	10
1985	7.1	-	-	-	3.0	-	-	-	-	10
1986	6.5	-	-	-	3.0	-	-	-	-	10
1987	8.9	-	-	-	3.0	-	-	-	-	12
1988	7.6	-	-	-	3.4	-	-	-	-	11
1989	8.5	-	-	-	3.5	-	-	-	-	12
1990	7.6	-	-	-	3.7	-	-	-	-	11
1995	7.5	-	-	-	5.0	-	-	-	-	13
2000	6.1	-	-	-	6.0	-	-	-	-	12
2005	8.5	-	-	-	8.3	-	-	-	-	17
2010	4.7	-	-	-	10.0	-	-	-	-	15
2015	4.5	-	-	-	12.8	-	-	-	-	17
2020	0.3	-	-	-	15.7	-	-	-	-	16

Table 2.7 (continued)

End of calendar year	Volume, 10^3 m^3									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Hanford Site					
1980	39.0	49.0	95.0	4.0	-	-	-	0.002	-	187
1981	39.0	49.0	95.0	4.0	-	-	-	0.002	-	187
1982	33.5	46.8	96.6	36.4	-	-	-	0.004	-	213
1983	29.8	46.7	93.8	59.1	-	-	-	0.004	-	229
1984	29.4	46.0	93.0	57.2	-	-	-	0.004	-	226
1985	28.1	46.0	93.0	55.1	-	-	-	0.004	-	222
1986	27.9	46.0	93.0	59.5	-	-	-	0.004	-	226
1987	27.3	46.0	93.0	73.4	-	-	-	0.004	-	240
1988	26.8	46.0	93.0	77.7	-	-	-	0.004	-	243
1989	26.5	46.0	93.0	79.3	-	-	-	0.004	-	245
1990	25.8	46.0	93.0	94.2	-	-	-	0.004	-	259
1995	11.5	46.0	93.0	94.5	-	-	-	0.004	-	245
2000	11.3	46.0	93.0	108.3	-	-	-	0.004	-	259
2005	11.3	46.0	93.0	110.3	-	-	-	0.004	-	261
2010	11.3	46.0	93.0	112.1	-	-	-	0.004	-	262
2015	11.3	46.0	93.0	114.0	-	-	-	0.004	-	264
2020	11.3	46.0	93.0	115.8	-	-	-	0.004	-	266
					West Valley Demonstration Project					
1980	2.150	0.046	-	-	-	-	-	-	-	2.196
1981	2.150	0.046	-	-	-	-	-	-	-	2.196
1982	2.150	0.046	-	-	-	-	-	-	-	2.196
1983	2.150	0.046	-	-	-	-	-	-	-	2.196
1984	2.150	0.046	-	-	-	-	-	-	-	2.196
1985	2.150	0.046	-	-	-	-	-	-	-	2.196
1986	2.150	0.046	-	-	-	-	-	-	-	2.196
1987	2.150	0.046	-	-	-	-	-	-	-	2.196
1988	2.070	0.046	-	-	-	-	0.013	-	-	2.129
1989	1.800	0.046	-	-	-	-	0.031	-	-	1.877
1990	1.507	0.046	-	-	-	-	0.072	-	-	1.625
1995	-	-	-	-	-	-	-	-	0.210	0.210
2000	-	-	-	-	-	-	-	-	0.210	0.210
2005	-	-	-	-	-	-	-	-	0.210	0.210
2010	-	-	-	-	-	-	-	-	0.210	0.210
2015	-	-	-	-	-	-	-	-	0.210	0.210
2020	-	-	-	-	-	-	-	-	0.210	0.210

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 5 (November 1989)]. The inventories for 1989 and the projections through 2020 are taken from refs. 1-4.

[b]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[c]Glass may be in storage at the site, in transit to a repository, or in a repository.

Table 2.8. Historical and projected total accumulative radioactivity of HLW in storage by site through 2020[a]

End of calendar year	Radioactivity, 10^6 Ci									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Savannah River Site					
1980	187.4	429.0	82.6	-	-	-	-	-	-	699
1981	165.6	722.0	94.4	-	-	-	-	-	-	982
1982	161.7	558.3	107.8	-	-	-	-	-	-	828
1983	85.9	509.2	181.1	-	-	-	-	-	-	776
1984	88.1	523.6	184.2	-	-	-	-	-	-	796
1985	93.3	561.3	186.8	-	-	-	-	-	-	841
1986	88.1	517.2	189.4	-	-	-	-	-	-	795
1987	105.2	460.4	168.2	-	-	0.2	-	-	-	734
1988	99.0	403.1	162.1	-	-	0.2	-	-	-	664
1989	94.6	351.2	152.8	-	-	0.3	-	-	-	599
1990	90.5	326.3	146.3	-	-	7.8	-	-	-	571
1995	67.5	359.1	115.1	-	-	20.8	-	-	150.0	713
2000	50.7	378.2	103.0	-	-	7.6	-	-	372.2	912
2005	42.5	464.2	84.4	-	-	6.0	-	-	449.3	1,046
2010	23.0	234.4	79.2	-	-	-	-	-	439.5	776
2015	17.0	240.7	72.8	-	-	2.9	-	-	390.9	724
2020	13.7	256.5	65.1	-	-	5.8	-	-	347.8	689
					Idaho Chemical Processing Plant					
1980	17.0	-	-	-	36.4	-	-	-	-	53
1981	26.4	-	-	-	37.2	-	-	-	-	64
1982	31.8	-	-	-	39.8	-	-	-	-	72
1983	16.2	-	-	-	48.6	-	-	-	-	65
1984	9.5	-	-	-	49.1	-	-	-	-	59
1985	21.7	-	-	-	47.7	-	-	-	-	69
1986	12.9	-	-	-	47.7	-	-	-	-	61
1987	14.3	-	-	-	48.2	-	-	-	-	63
1988	10.1	-	-	-	56.9	-	-	-	-	67
1989	11.5	-	-	-	56.9	-	-	-	-	68
1990	6.6	-	-	-	59.5	-	-	-	-	66
1995	7.3	-	-	-	75.9	-	-	-	-	83
2000	3.6	-	-	-	92.0	-	-	-	-	96
2005	23.6	-	-	-	141.1	-	-	-	-	165
2010	15.9	-	-	-	161.5	-	-	-	-	177
2015	25.1	-	-	-	227.2	-	-	-	-	252
2020	3.7	-	-	-	280.6	-	-	-	-	284

Table 2.8 (continued)

End of calendar year	Radioactivity, 10^6 Ci									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Hanford Site					
1980	34.6	175.0	16.0	0.3	-	-	-	332.0	-	558
1981	34.0	163.0	15.0	0.2	-	-	-	319.0	-	531
1982	33.5	140.2	14.6	0.2	-	-	-	228.2	-	417
1983	29.2	136.9	14.2	3.8	-	-	-	223.0	-	407
1984	28.1	133.7	13.9	147.8	-	-	-	217.8	-	541
1985	26.2	130.5	13.6	171.4	-	-	-	212.8	-	554
1986	25.5	127.4	13.2	187.6	-	-	-	207.9	-	562
1987	24.4	124.4	12.9	116.0	-	-	-	203.1	-	481
1988	23.3	121.4	12.6	111.1	-	-	-	177.1	-	446
1989	22.6	118.5	12.3	89.8	-	-	-	173.2	-	416
1990	21.5	115.7	12.1	75.2	-	-	-	169.3	-	394
1995	8.5	102.7	10.7	110.7	-	-	-	150.6	-	383
2000	7.5	91.1	9.5	101.8	-	-	-	134.1	-	344
2005	6.7	80.8	8.5	89.5	-	-	-	119.3	-	305
2010	5.9	71.7	7.5	79.4	-	-	-	106.2	-	271
2015	5.3	63.6	6.7	70.6	-	-	-	94.5	-	241
2020	4.7	56.4	6.0	62.8	-	-	-	84.1	-	214
					West Valley Demonstration Project					
1980	18.2	16.0	-	-	-	-	-	-	-	34.2
1981	17.8	15.6	-	-	-	-	-	-	-	33.4
1982	17.4	15.3	-	-	-	-	-	-	-	32.7
1983	17.0	14.9	-	-	-	-	-	-	-	31.9
1984	16.6	14.6	-	-	-	-	-	-	-	31.2
1985	16.2	14.2	-	-	-	-	-	-	-	30.4
1986	15.8	13.9	-	-	-	-	-	-	-	29.7
1987	15.5	13.7	-	-	-	-	-	-	-	29.2
1988	14.6	13.4	-	-	-	-	0.7	-	-	28.7
1989	13.0	13.0	-	-	-	-	1.9	-	-	27.9
1990	10.3	12.7	-	-	-	-	4.3	-	-	27.2
1995	-	-	-	-	-	-	-	-	24.2	24.2
2000	-	-	-	-	-	-	-	-	21.5	21.5
2005	-	-	-	-	-	-	-	-	19.1	19.1
2010	-	-	-	-	-	-	-	-	17.0	17.0
2015	-	-	-	-	-	-	-	-	15.1	15.1
2020	-	-	-	-	-	-	-	-	13.4	13.4

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 5 (November 1989)]. The inventories for 1989 and the projections through 2020 are taken from refs. 1-4.

[b]Capsules contain either strontium (^{90}Sr-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

[c]Glass may be in storage at the site, in transit to a repository, or in a repository.

Table 2.9. Historical and projected total accumulative thermal power of HLW in storage by site through 2020[a]

End of calendar year	Thermal power, 10^3 W									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Savannah River Site					
1980	213.5	1,440.5	396.0	-	-	-	-	-	-	2,050
1981	302.1	2,037.8	560.1	-	-	-	-	-	-	2,900
1982	259.4	1,749.7	480.9	-	-	-	-	-	-	2,490
1983	237.5	1,601.7	440.4	-	-	-	-	-	-	2,280
1984	244.8	1,650.9	453.9	-	-	-	-	-	-	2,350
1985	264.3	1,782.7	490.2	-	-	-	-	-	-	2,537
1986	302.2	1,794.1	479.0	-	-	-	-	-	-	2,575
1987	279.8	1,438.9	432.8	-	-	0.4	-	-	-	2,152
1988	231.9	1,280.5	370.9	-	-	0.4	-	-	-	1,884
1989	217.7	1,105.8	349.5	-	-	0.7	-	-	-	1,674
1990	207.4	1,036.1	334.8	-	-	17.9	-	-	-	1,596
1995	171.2	1,147.0	267.7	-	-	47.7	-	-	412.5	2,046
2000	142.0	1,277.4	242.9	-	-	17.8	-	-	1,104.0	2,784
2005	132.3	1,586.1	201.1	-	-	14.0	-	-	1,355.0	3,289
2010	66.9	750.3	187.8	-	-	-	-	-	1,340.0	2,345
2015	51.9	739.8	172.8	-	-	6.9	-	-	1,199.0	2,170
2020	44.1	852.4	154.6	-	-	13.9	-	-	1,074.0	2,139
					Idaho Chemical Processing Plant					
1980	53.8	-	-	-	115.2	-	-	-	-	169
1981	88.3	-	-	-	121.7	-	-	-	-	210
1982	88.8	-	-	-	128.2	-	-	-	-	217
1983	55.2	-	-	-	134.8	-	-	-	-	190
1984	29.5	-	-	-	141.3	-	-	-	-	171
1985	72.5	-	-	-	137.4	-	-	-	-	210
1986	38.5	-	-	-	137.4	-	-	-	-	176
1987	43.5	-	-	-	139.0	-	-	-	-	183
1988	30.4	-	-	-	165.2	-	-	-	-	196
1989	34.3	-	-	-	164.9	-	-	-	-	199
1990	19.3	-	-	-	172.9	-	-	-	-	192
1995	21.2	-	-	-	241.6	-	-	-	-	263
2000	10.6	-	-	-	277.8	-	-	-	-	288
2005	72.1	-	-	-	482.7	-	-	-	-	555
2010	49.6	-	-	-	521.3	-	-	-	-	571
2015	77.0	-	-	-	742.4	-	-	-	-	819
2020	11.3	-	-	-	819.1	-	-	-	-	830

Table 2.9 (continued)

End of calendar year	Thermal power, 10^3 W									
	Liquid	Sludge	Salt cake	Slurry	Calcine	Precipitate	Zeolite	Capsules[b]	Glass[c]	Total
					Hanford Site					
1980	75.1	325.9	32.8	0.5	-	-	-	644.4	-	1,079
1981	114.0	495.0	49.7	0.8	-	-	-	978.5	-	1,638
1982	84.3	460.3	41.1	0.5	-	-	-	625.2	-	1,212
1983	73.3	449.5	40.0	9.6	-	-	-	610.8	-	1,183
1984	70.7	438.7	39.1	556.8	-	-	-	596.7	-	1,702
1985	65.9	428.3	38.2	604.5	-	-	-	582.9	-	1,720
1986	64.1	418.1	37.3	636.1	-	-	-	569.4	-	1,725
1987	61.2	408.1	36.4	354.0	-	-	-	556.3	-	1,416
1988	58.6	398.4	35.5	329.1	-	-	-	487.6	-	1,309
1989	56.7	389.0	34.7	250.2	-	-	-	476.9	-	1,207
1990	54.0	379.7	33.9	202.1	-	-	-	465.8	-	1,135
1995	21.5	336.7	30.1	310.1	-	-	-	414.5	-	1,113
2000	18.8	298.6	26.8	292.7	-	-	-	368.8	-	1,006
2005	16.8	264.8	23.8	260.3	-	-	-	328.1	-	894
2010	14.9	234.9	21.2	232.4	-	-	-	291.9	-	795
2015	13.3	208.4	18.8	207.8	-	-	-	259.7	-	708
2020	11.9	184.9	16.7	186.0	-	-	-	231.1	-	631
					West Valley Demonstration Project					
1980	46.9	55.1	-	-	-	-	-	-	-	102
1981	45.7	53.9	-	-	-	-	-	-	-	100
1982	44.5	52.7	-	-	-	-	-	-	-	97
1983	43.4	51.6	-	-	-	-	-	-	-	95
1984	42.3	50.5	-	-	-	-	-	-	-	93
1985	41.2	49.3	-	-	-	-	-	-	-	91
1986	40.3	48.1	-	-	-	-	-	-	-	88
1987	38.0	47.5	-	-	-	-	-	-	-	86
1988	37.1	46.5	-	-	-	-	1.7	-	-	85
1989	33.4	45.2	-	-	-	-	4.6	-	-	83
1990	25.9	44.6	-	-	-	-	10.7	-	-	81
1995	-	-	-	-	-	-	-	-	72.0	72
2000	-	-	-	-	-	-	-	-	64.2	64
2005	-	-	-	-	-	-	-	-	57.2	57
2010	-	-	-	-	-	-	-	-	51.0	51
2015	-	-	-	-	-	-	-	-	45.5	46
2020	-	-	-	-	-	-	-	-	40.6	41

[a]Historical inventories for HLW are taken from the previous edition of this report [i.e., DOE/RW-0006, Rev. 5 (November 1989)]. The inventories for 1989 and the projections through 2020 are taken from refs. 1–4.

[b]Capsules contain either strontium (^{90}Sr–^{90}Y) fluoride or cesium (^{137}Cs–^{137m}Ba) chloride.

[c]Glass may be in storage at the site, in transit to a repository, or in a repository.

Table 2.10. Significant revisions and changes in the current values for HLW compared to the values in the previous year

Waste characteristics	1988 values[a]	Significant revisions and changes	1989 values	Reasons for significant changes and revisions or for none
		Savannah River Site		
Volume and radioactivity (liquid, sludge, salt cake, and precipitate)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	No revisions. Changes are explained by routine plant operations and decay of radionuclides
		Idaho Chemical Processing Plant		
Volume and radioactivity (liquid and calcine)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	No revisions. Changes are explained by routine plant operations and decay of radionuclides
		Hanford Site		
Volume and radioactivity (liquid, sludge, salt cake, slurry, as well as Sr and Cs capsules)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	No significant revisions. Changes are explained by routine plant operation
		West Valley Demonstration Project		
Volume (alkaline liquid and zeolite)	See Tables 2.5 and 2.6	None	See Tables 2.5 and 2.6	Changes in volume are explained by routine plant operations in preparation for operation of West Valley Vitrification Facility in late 1993
Radioactivity (acid liquid, alkaline liquid, sludge, and zeolite)	See Tables 2.5, 2.6, and 2.20	Reference radionuclide composition has been revised downward	See Tables, 2.5, 2.6, and 2.20	Changes are explained by routine plant operations and by revisions in the WVDP program for calculation of radioactive decay

[a]See tables cited in Chapter 2 of U.S. Department of Energy, Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 5 (November 1989).

Table 2.11. Representative chemical composition of current and future HLW at SRS[a]

Liquid		Sludge		Salt cake		Precipitate[b]		Glass	
Component	Wt %	Component	Wt %	Component	Wt %	Component	Wt %	Component	Wt %
Ag	Trace	$Fe(OH)_3$	11.8	$NaNO_3$	65.4	$K(C_6H_5)_4B$	9.0	SiO_2	45.6
Hg	Trace	MnO_2	2.0	$NaNO_2$	0.9	$NaNO_3$	0.7	Na_2O	11.0
Pb	Trace	$UO_2(OH)_2$	1.3	NaOH	3.4	Others	1.8	B_2O_3	10.3
U	Trace	$Al(OH)_3$	13.7	$NaAl(OH)_4$	7.8	H_2O	88.5	Fe_2O_3	7.0
F	0.003	AlO(OH)	5.2	Na_2CO_3	2.7		100.0	Al_2O_3	4.0
Fe	Trace	$CaCO_3$	1.5	Na_2SO_4	9.4			K_2O	3.6
Cl^-	0.023	$CaSO_4$	0.2	Na_3PO_4	Trace			Li_2O	3.2
OH^-	1.63	CaC_2O_4	0.2	NaF	0.2			FeO	3.1
NO_2^-	1.10	$Ni(OH)_2$	0.8	$Na_2C_2O_4$	0.1			U_3O_8	2.2
NO_3^-	9.63	HgO	0.4	Insolubles	3.7			MnO	2.0
$Al(OH)_4^-$	4.54	SiO_2	0.2	H_2O	6.4			Other	8.0
CO_3^{2-}	0.72	ThO_2	1.8		100.0				100.0
CrO_4^{2-}	0.014	$Ce(OH)_3$	0.2						
SO_4^{2-}	0.22	$ZrO(OH)_2$	0.2						
PO_4^{3-}	0.12	$Cr(OH)_3$	0.2						
NH_4^+	Trace	$Mg(OH)_2$	0.2						
Na	11.0	$NaNO_3$	1.1						
H_2O	71.0	NaOH	1.3						
		Zeolite	1.5						
	100.0	Others	1.2						
		H_2O	55.0						
			100.0						
Density (25°C), g/mL	1.1		1.4		1.9		1.05		2.85

[a]Taken from ref. 1.
[b]Precipitate (non-Newtonian fluid) from the in-tank precipitation process.

Table 2.12. Representative radionuclide composition of current (1989) HLW and HLW glass to be generated in 1992 at SRS[a]

Radionuclide	Radioactivity, Ci					
	Liquid	Sludge	Salt cake	Precipitate	Total	Glass
^{89}Sr	-	2.00E+02	-	-	2.00E+02	-
^{90}Sr	8.29E+05	1.30E+08	1.32E+06	4.00E+03	1.32E+08	1.12E+06
^{90}Y	8.29E+05	1.30E+08	1.32E+06	4.00E+03	1.32E+08	1.12E+06
^{91}Y	-	1.00E+03	-	-	1.00E+03	-
^{95}Zr	-	3.00E+03	-	-	3.00E+03	-
^{95}Nb	1.00E+03	7.00E+03	-	-	8.00E+03	-
^{99}Tc	6.00E+03	2.09E+05	2.20E+04	-	2.37E+05	1.70E+03
^{106}Ru	3.15E+05	1.29E+06	1.20E+04	-	1.62E+06	-
^{106}Rh	3.15E+05	1.29E+06	1.20E+04	-	1.62E+06	-
^{125}Sb	1.45E+05	3.51E+05	3.00E+03	-	4.99E+05	1.10E+02
^{137}Cs	4.66E+07	1.19E+07	7.80E+07	1.59E+05	1.37E+08	1.05E+07
^{137m}Ba	4.28E+07	1.09E+07	7.18E+07	1.46E+05	1.26E+08	9.66E+06
^{144}Ce	6.09E+05	1.24E+07	1.40E+04	-	1.30E+07	-
^{144}Pr	6.09E+05	1.24E+07	1.40E+04	-	1.30E+07	-
^{147}Pm	1.56E+06	3.76E+07	3.66E+05	-	3.95E+07	7.00E+03
^{233}U	-	2.48E-01	-	-	2.48E-01	1.86E-02
^{235}U	-	2.62E-01	-	-	2.62E-01	1.97E-02
^{238}U	-	2.19E+01	-	-	2.19E+01	1.50E+00
^{238}Pu	-	1.60E+06	-	-	1.60E+06	1.07E+05
^{239}Pu	-	2.20E+04	-	-	2.20E+04	1.62E+03
^{240}Pu	-	1.04E+04	-	-	1.04E+04	6.99E+02
^{241}Pu	-	1.42E+06	-	-	1.42E+06	8.29E+04
^{242}Pu	-	1.70E+01	-	-	1.70E+01	1.15E+00
^{244}Cm	-	1.47E+04	-	-	1.47E+04	8.79E+02
Total	9.46E+07	3.51E+08	1.53E+08	3.13E+05	5.96E+08	2.26E+07
Specific activity, Ci/L	1.77	25.5	2.79	2.48	4.88	251

[a]Taken or calculated from ref. 1. Liquid, sludge, salt cake, and precipitate curies are as of December 31, 1989. Glass curies are as of December 31, 1992 (the first year glass is to be generated). Liquid, sludge, salt cake, and precipitate will continue to be waste types in 1992.

Table 2.13. Representative chemical composition of current and future HLW liquid at ICPP[a]

Component	Composition, wt %			
	Zirconium fluoride	Sodium bearing	Nonfluoride	Fluorinel
Al	1.3	0.8-1.6	1.51	0.742
B	0.15	0.005-0.01	0.003	0.241
Ca	–	0.03-0.2	0.27	–
Cl^-	–	0.06-0.1	0.023	–
Cd	–	–	1.42	–
Cr	–	–	0.036	0.0087
F^-	3.4	0.005-0.06	0.032	5.99
Fe	0.04	0.05-0.09	0.19	0.023
H^+	1.12	0.03-0.15	0.12	0.18
K	1.12	0.03-0.15	0.33	–
Mg	–	–	0.062	–
Mn	–	–	0.048	0.0004
Na	0.12	2.1-4.0	1.31	–
Ni	–	–	0.016	0.0049
NO_3^-	13.7	19.4-23.3	23.1	11.47
SO_4^{2-}	–	0.33-0.5	0.65	1.52
Zr	2.47	–	–	3.80
H_2O	76.6	76.6-69.2	70.9	76.0
	100.0	100.0	100.0	100.0
Density, g/mL	1.2	1.2-1.3	1.2	1.2

[a]Taken from U.S. Department of Energy, Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1 (December 1985).

Table 2.14. Representative chemical composition of current and future HLW calcine at ICPP[a]

Component	Composition, wt %				
	Alumina	Zirconium fluoride	Zirconium-sodium blend	Stainless steel sulfate	Fluorinel-sodium blend
Al_2O_3	82.0–95.0	13.0–17.0	10.0–16.0	4.4	6.5–7.5
$Al_2(SO_4)_3$	–	–	–	81.0	–
B_2O_3	0.5–2.0	3.0–4.0	2.0–3.0	–	3.0–3.2
CaO	–	2.0–4.0	13.0–17.0	–	3.3–3.6
CaF_2	–	50.0–56.0	33.0–39.0	–	46.0–49.0
Cd	–	–	–	–	6.0–6.5
Cr_2O_3	–	–	–	2.0	0.05
Fe_2O_3	–	–	–	7.0	0.2–0.3
Na_2O	1.3	–	6.0–8.0	–	10.0–15.0
NiO	–	–	–	0.9	0.02–0.03
NO_3^-	5.0–9.0	0.5–2.0	7.0–9.5	–	10.0–15.0
SO_4^{2-}	–	–	–	–	–
ZrO_2	–	21.0–27.0	16.0–19.0	–	19.0–20.0
Miscellaneous	0.5–1.5	0.5–1.5	0.5–1.5	4.4	–
Fission products and actinides	0.2–1.0	0.2–1.0	0.2–1.0	0.2–1.0	0.2–1.0
Density, g/mL	1.1	1.4	1.8	1.2	1.4

[a]Taken from U.S. Department of Energy, Spent Fuel And Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1 (December 1985).

Table 2.15. Representative chemical composition of current and future HLW at HANF[a]

Component	Composition, wt %			
	Liquid[b]	Sludge[b]	Salt cake[b]	Slurry[c]
$NaNO_3$	20.8	25.3	81.5	14.8
$NaNO_2$	15.8	3.8	1.7	5.6
Na_2CO_3	0.6	2.2	0.5	1.9
NaOH	6.2	5.3	1.5	7.0
$NaAlO_2$	12.5	1.2	1.4	6.0
NaF	–	–	–	0.4
Na_2SO_4	–	1.0	1.3	0.3
Na_3PO_4	2.3	15.8	1.6	0.8
KF	–	–	–	0.4
FeO(OH)	–	1.3	–	0.2
Organic carbon	0.17	–	–	1.2
NH_4^+	–	–	–	0.08
$Al(OH)_3$	–	2.9	–	4.9
$SrO \cdot H_2O$	–	0.1	–	–
Na_2CrO_4	1.3	–	–	–
$Cr(OH)_3$	–	0.2	–	0.02
$Cd(OH)_2$	–	0.1	–	–
$Ni(OH)_2$	–	–	–	<0.1
$BiPO_4$	–	0.5	–	–
Cl^-	–	0.1	–	–
$Ni_2Fe(CN)_6$	–	0.6	–	–
$P_2O_5 \cdot 24WO_2 \cdot 44H_2O$	–	<0.1	–	–
$ZrO_2 \cdot 2H_2O$	–	0.5	–	0.2
Fission products	–	–	–	<0.01
H_2O	40.2	33.6	10.5	56.2
Other	<0.1	5.5	–	<0.01
Hg^+	–	0.12 ppm	–	–
Total	100.0	100.0	100.0	100.0
Density, g/mL	1.6	1.7	1.4	~1.3

[a]Taken from U.S. Department of Energy, Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 1 (December 1985).

[b]Stored in single-shell tanks.

[c]Stored in double-shell tanks.

Table 2.16. Representative radionuclide composition (Ci) of current HLW at HANF[a]

Radionuclide	Liquid	Sludge	Salt cake	Slurry	Capsules	
					^{90}Sr-^{90}Y	^{137}Cs-^{137m}Ba
^{14}C	1.98E+03	-	2.50E+03	5.49E+02	-	-
^{55}Fe	-	-	-	2.53E+03	-	-
^{60}Co	-	4.78E+03	-	9.57E+03	-	-
^{59}Ni	-	-	-	3.12E+00	-	-
^{63}Ni	-	3.14E+05	-	6.84E+02	-	-
^{79}Se	-	-	-	6.62E+01	-	-
^{89}Sr	-	-	-	3.10E+03	-	-
^{90}Sr	4.69E+05	5.49E+07	2.36E+06	1.18E+07	2.73E+07	-
^{90}Y	4.69E+05	5.49E+07	2.36E+06	1.18E+07	2.73E+07	-
^{91}Y	-	-	-	2.92E+04	-	-
^{93}Zr	-	9.70E+03	-	3.19E+02	-	-
^{95}Zr	-	-	-	1.01E+03	-	-
^{93m}Nb	-	7.98E+03	-	7.93E+01	-	-
^{95}Nb	-	-	-	2.27E+03	-	-
^{95m}Nb	-	-	-	7.56E+00	-	-
^{99}Tc	1.90E+04	-	-	1.32E+04	-	-
^{103}Ru	-	-	-	4.09E-01	-	-
^{103m}Rh	-	-	-	3.60E-01	-	-
^{106}Ru	-	7.72E+01	-	2.39E+06	-	-
^{106}Rh	-	7.72E+01	-	2.39E+06	-	-
^{107}Pd	-	-	-	8.26E+00	-	-
^{110}Ag	-	-	-	4.57E+00	-	-
^{110m}Ag	-	-	-	3.44E+02	-	-
^{113m}Cd	-	-	-	4.34E+03	-	-
^{115m}Cd	-	-	-	5.09E+00	-	-
^{113}Sn	-	-	-	2.65E+01	-	-
^{119m}Sn	-	-	-	7.21E+03	-	-
^{121m}Sn	-	-	-	5.54E+01	-	-
^{123}Sn	-	-	-	6.34E+02	-	-
^{126}Sn	-	-	-	1.05E+02	-	-
^{124}Sb	-	-	-	1.36E-02	-	-
^{125}Sb	-	-	-	6.36E+05	-	-
^{126}Sb	-	-	-	1.47E+01	-	-
^{126m}Sb	-	-	-	1.16E+02	-	-
^{123m}Te	-	-	-	4.82E-13	-	-
^{125m}Te	-	-	-	1.55E+05	-	-
^{127}Te	-	-	-	7.00E+02	-	-
^{127m}Te	-	-	-	7.14E+02	-	-
^{129}Te	-	-	-	3.53E-04	-	-
^{129m}Te	-	-	-	5.42E-04	-	-
^{129}I	-	-	-	2.67E-01	-	-
^{134}Cs	-	-	-	3.85E+05	-	-
^{135}Cs	-	-	-	5.95E+01	-	-
^{137}Cs	1.11E+07	3.86E+06	3.92E+06	1.67E+07	-	6.10E+07
^{137m}Ba	1.05E+07	3.66E+06	3.71E+06	1.58E+07	-	5.77E+07
^{141}Ce	-	-	-	1.16E-02	-	-
^{144}Ce	-	-	-	6.71E+06	-	-
^{144}Pr	-	-	-	6.69E+06	-	-
^{144m}Pr	-	-	-	8.04E+04	-	-
^{147}Pm	-	-	-	1.36E+07	-	-
^{148}Pm	-	-	-	4.86E-04	-	-
^{148m}Pm	-	-	-	8.63E-03	-	-
^{151}Sm	-	8.53E+05	-	2.37E+05	-	-
^{152}Eu	-	-	-	6.34E+02	-	-
^{154}Eu	-	-	-	8.65E+04	-	-
^{155}Eu	-	-	-	1.52E+05	-	-
^{153}Gd	-	-	-	2.49E+00	-	-

Table 2.16 (continued)

Radionuclide	Liquid	Sludge	Salt cake	Slurry	Capsules	
					^{90}Sr-^{90}Y	^{137}Cs-^{137m}Ba
^{160}Tb	-	-	-	3.57E-02	-	-
^{234}U	-	-	-	6.70E-03	-	-
^{235}U	-	-	-	5.14E-02	-	-
^{236}U	-	-	-	1.20E-01	-	-
^{238}U	-	-	-	9.48E-01	-	-
^{237}Np	1.90E-03	-	-	4.05E+01	-	-
^{238}Np	-	-	-	2.60E-01	-	-
^{238}Pu	-	-	-	2.98E+02	-	-
^{239}Pu	-	2.20E+04	-	3.35E+03	-	-
^{240}Pu	-	5.30E+03	-	9.09E+02	-	-
^{241}Pu	-	6.07E+04	-	3.84E+04	-	-
^{242}Pu	-	-	-	9.34E-02	-	-
^{241}Am	7.83E+02	4.45E+04	-	5.32E+04	-	-
^{242}Am	-	-	-	5.11E+01	-	-
^{242m}Am	-	-	-	5.14E+01	-	-
^{243}Am	-	-	-	3.01E+01	-	-
^{242}Cm	-	-	-	5.72E+01	-	-
^{244}Cm	-	1.76E+02	-	1.21E+02	-	-
Total	2.26E+07	1.19E+08	1.24E+07	8.98E+07	5.46E+07	1.19E+08
Specific activity, Ci/L	8.5E-01	2.6E+00	1.3E-01	1.1E+00	5.1E+04	4.8E+04

[a]Taken from ref. 3. Curies as of December 31, 1989.

Table 2.17. Chemical composition of alkaline liquid HLW (from reprocessing via a PUREX flowsheet) at WVDP[a]

Compound	Wet basis (wt %)	Dry basis (wt %)	Total (kg)
$NaNO_3$	21.10	53.38	602,659
$NaNO_2$	10.90	27.57	311,326
Na_2SO_4	2.67	6.75	76,261
$NaHCO_3$	1.49	3.77	42,557
KNO_3	1.27	3.21	36,274
Na_2CO_3	0.884	2.24	25,249
NaOH	0.614	1.55	17,537
K_2CrO_4	0.179	0.45	5,113
NaCl	0.164	0.42	4,684
Na_3PO_4	0.133	0.34	3,799
Na_2MoO_4	0.0242	0.06	691
Na_3BO_3	0.0209	0.05	597
$CsNO_3$	0.0187	0.05	534
NaF	0.0176	0.04	503
$Sn(NO_3)_4$	0.00858	0.02	245
$Na_2U_2O_7$	0.00809	0.02	231
$Si(NO_3)_4$	0.00805	0.02	230
$NaTcO_4$	0.00620	0.02	177
$RbNO_3$	0.00417	0.01	119
Na_2TeO_4	0.00287	0.007	82
AlF_3	0.0027	0.0068	77
$Fe(NO_3)_3$	0.00151	0.004	43
Na_2SeO_4	0.00053	0.0013	15
$LiNO_3$	0.00049	0.0012	14
H_2CO_3	0.00032	0.00080	9
$Cu(NO_3)_3$	0.00021	0.00053	6
$Sr(NO_3)_2$	0.00014	0.00035	4
$Mg(NO_3)_2$	0.00007	0.00018	2
Subtotal	39.53	100.00	1,129,038
H_2O (by difference)	60.47	0.00	1,727,116
Grand total	100.00	100.00	2,856,154

[a]Taken from ref. 4.

Table 2.18. Chemical composition of alkaline sludge HLW (from reprocessing via a PUREX flowsheet) at WVDP[a]

Compound	Weight, kg
Fission products	
$Ge(OH)_3$	0.2
$SrSO_4$	217
$Y(OH)_3$	103
$Zr(OH)_4$	964
$Ru(OH)_4$	458
$Rh(OH)_4$	79
$Pd(OH)_2$	34
AgOH	0.7
$Cd(OH)_2$	1.7
$In(OH)_3$	0.3
$Sn(OH)_4$	2.5
$Sb(OH)_3$	0.7
$BaSO_4$	303
$La(OH)_3$	185
$Ce(OH)_3$	354
$Pr(OH)_3$	170
$Nd(OH)_3$	621
$Pm(OH)_3$	1.5
$Sm(OH)_3$	143
$Eu(OH)_3$	7.5
$Gd(OH)_3$	1.7
$Tb(OH)_3$	0.3
$Dy(OH)_3$	0.2
Subtotal	3,648.3
Actinides	
$UO_2(OH)_2$	3,087
NpO_2	35
PuO_2	37
AmO_2	27
CmO_2	0.4
Subtotal	3,186.4
Others	
$Fe(OH)_3$	66,040
$FePO_4$	6,351
$Al(OH)_3$	5,852
AlF_3	613
MnO_2	4,581
$CaCO_3$	3,208
SiO_2	1,263
$Ni(OH)_2$	1,088
$MgCO_3$	826
$Cu(OH)_2$	376
$Zr(OH)_4$	964[b]
$Zn(OH)_2$	128
$Cr(OH)_3$	65
$Hg(OH)_2$	23
Subtotal	91,378
Grand total	98,213

[a]Taken from ref. 4.
[b]Excludes fission product zirconium.

Table 2.19. Chemical composition of acid liquid HLW (from reprocessing via a THOREX flowsheet) at WVDP[a]

Compound	Wt %	Total, kg
$Th(NO_3)_4$	36.42	31,054
$Fe(NO_3)_3$	9.92	8,462
$Al(NO_3)_3$	4.90	4,175
HNO_3	3.29	2,805
$Cr(NO_3)_3$	2.25	1,918
$Ni(NO_3)_2$	0.93	79
H_3BO_3	0.56	480
$NaNO_3$	0.27	227
KNO_3	0.22	191
Na_2SO_4	0.21	180
Na_2SiO_3	0.15	126
$KMnO_4$	0.11	98
$Nd(NO_3)_3$	0.086	73
$Mg(NO_3)_2$	0.067	57
Na_2MoO_4	0.063	54
NaCl	0.059	50
$Ce(NO_3)_4$	0.050	43
$Ru(NO_3)_4$	0.049	42
ZrO_2	0.041	35
$Ca(NO_3)_2$	0.035	30
$CsNO_3$	0.033	28
$Ba(NO_3)_2$	0.032	27
$La(NO_3)_3$	0.026	22
$Pr(NO_3)_3$	0.025	21
$Sr(NO_3)_2$	0.019	16
$Y(NO_3)_3$	0.016	14
$Sm(NO_3)_3$	0.016	14
$Zr(NO_3)_4$	0.014	12
Na_3PO_4	0.014	12
$NaTcO_4$	0.013	11
$Rh(NO_3)_4$	0.013	11
$Zn(NO_3)_2$	0.012	10
$Pd(NO_3)_4$	0.0094	8
$UO_2(NO_3)_2$	0.0070	6
$RbNO_3$	0.0070	6
Na_2TeO_4	0.0059	5
$Co(NO_3)_2$	0.0035	3
Na_2SeO_4	0.0012	1
NaF	0.0012	1
$Eu(NO_3)_3$	0.0012	1
$Np(NO_3)_4$	0.0011	0.9
$Cu(NO_3)_2$	0.00094	0.8
$Sn(NO_3)_3$	0.00082	0.7
$Pa(NO_3)_4$	0.00082	0.7
$Pu(NO_3)_4$	0.00082	0.7
$Gd(NO_3)_3$	0.00047	0.4
$Cd(NO_3)_2$	0.00035	0.3
$Sb(NO_3)_3$	0.00012	0.1
$AgNO_3$	0.000094	0.08
$In(NO_3)_3$	0.000047	0.04
$Ge(NO_3)_4$	0.000023	0.02
$Pm(NO_3)_2$	0.000011	0.01
$Tb(NO_3)_3$	0.0000047	0.004
$Dy(NO_3)_3$	0.0000023	0.002
Solids	59.95	51,125
H_2O (by difference)	40.05	34,148
Total	100.00	85,273

[a]Adapted from ref. 4.

Table 2.20. Reference 1990 radionuclide composition of HLW at WVDP[a,b]

Radionuclide	Alkaline waste (PUREX) Liquid (Ci)	Alkaline waste (PUREX) Sludge (Ci)	Acid waste (THOREX) Liquid (Ci)	Zeolite waste (Ion exchanger) Slurry (Ci)	Total (Ci)
^{3}H	8.23E+01	0.00E+00	1.47E+00	0.00E+00	8.38E+01
^{14}C	1.37E+02	0.00E+00	1.30E-01	0.00E+00	1.37E+02
^{55}Fe	0.00E+00	4.49E+02	2.53E+02	0.00E+00	7.02E+02
^{60}Co	0.00E+00	3.17E+00	7.68E+02	0.00E+00	7.71E+02
^{59}Ni	0.00E+00	8.56E+01	2.03E+01	0.00E+00	1.06E+02
^{63}Ni	8.69E+02	5.22E+03	2.45E+03	0.00E+00	8.54E+03
^{79}Se	5.68E+01	0.00E+00	3.35E+00	0.00E+00	6.01E+01
^{90}Sr	2.69E+03	6.28E+06	4.23E+05	0.00E+00	6.70E+06
^{90}Y	2.69E+03	6.28E+06	4.23E+05	0.00E+00	6.70E+06
^{93}Zr	2.56E-01	2.56E+02	1.62E+01	0.00E+00	2.72E+02
^{93m}Nb	1.73E-01	1.71E+02	1.11E+01	0.00E+00	1.82E+02
^{99}Tc	1.60E+03	0.00E+00	1.04E+02	0.00E+00	1.70E+03
^{106}Ru	1.40E-02	1.40E+01	7.96E-02	0.00E+00	1.41E+01
^{106}Rh	1.40E-02	1.40E+01	7.96E-02	0.00E+00	1.41E+01
^{107}Pd	1.09E-02	1.09E+01	1.14E-01	0.00E+00	1.10E+01
^{113m}Cd	2.09E+00	2.09E+03	3.25E+01	0.00E+00	2.12E+03
^{121m}Sn	1.69E-02	1.69E+01	5.75E-01	0.00E+00	1.75E+01
^{126}Sn	1.01E-01	1.01E+02	3.11E+00	0.00E+00	1.04E+02
^{125}Sb	2.31E+01	7.13E+03	1.36E+02	0.00E+00	7.29E+03
^{126}Sb	1.41E-02	1.41E+01	4.35E-01	0.00E+00	1.46E+01
^{126m}Sb	1.01E-01	1.01E+02	3.11E+00	0.00E+00	1.04E+02
^{125m}Te	5.67E+00	1.75E+03	3.34E+01	0.00E+00	1.79E+03
^{129}I	2.10E-01	0.00E+00	1.80E-01	0.00E+00	3.90E-01
^{134}Cs	4.35E+03	0.00E+00	1.13E+02	7.15E+02	5.18E+03
^{135}Cs	1.34E+02	0.00E+00	5.47E+00	2.20E+01	1.61E+02
^{137}Cs	5.81E+06	0.00E+00	4.43E+05	9.55E+05	7.22E+06
^{137m}Ba	5.51E+06	0.00E+00	4.19E+05	9.04E+05	6.83E+06
^{144}Ce	1.45E-06	6.38E-01	9.63E-03	0.00E+00	6.48E-01
^{144}Pr	1.45E-06	6.38E-01	9.63E-03	0.00E+00	6.48E-01
^{146}Pm	3.27E-02	1.05E+01	3.47E-01	0.00E+00	1.09E+01
^{147}Pm	2.58E+02	8.37E+04	4.12E+03	0.00E+00	8.80E+04
^{151}Sm	4.92E-01	7.96E+04	4.67E+03	0.00E+00	8.43E+04
^{152}Eu	3.92E-02	3.24E+02	4.14E+01	0.00E+00	3.65E+02
^{154}Eu	1.13E+01	9.34E+04	1.99E+03	0.00E+00	9.54E+04
^{155}Eu	1.56E+00	2.33E+04	5.55E+02	0.00E+00	2.38E+04
^{207}Tl	1.87E-08	8.55E-04	8.19E+00	0.00E+00	8.19E+00
^{208}Tl	7.31E-02	1.04E+00	2.18E+00	0.00E+00	3.29E+00
^{209}Pb	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{211}Pb	1.88E-08	8.57E-04	8.22E+00	0.00E+00	8.22E+00
^{212}Pb	2.04E-01	2.88E+00	6.08E+00	0.00E+00	9.17E+00
^{211}Bi	1.88E-08	8.57E-04	8.22E+00	0.00E+00	8.22E+00
^{212}Bi	2.04E-01	2.88E+00	6.08E+00	0.00E+00	9.17E+00
^{213}Bi	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{212}Po	1.30E-01	1.85E+00	3.90E+00	0.00E+00	5.88E+00
^{213}Po	1.38E-04	1.93E-03	2.03E-01	0.00E+00	2.05E-01
^{215}Po	1.88E-08	8.57E-04	8.22E+00	0.00E+00	8.22E+00
^{216}Po	2.04E-01	2.88E+00	6.08E+00	0.00E+00	9.17E+00
^{217}At	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{219}Rn	1.88E-08	8.57E-04	8.22E+00	0.00E+00	8.22E+00
^{220}Rn	2.04E-01	2.88E+00	6.08E+00	0.00E+00	9.17E+00
^{221}Fr	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{223}Fr	2.59E-10	1.18E-05	1.13E-01	0.00E+00	1.13E-01
^{223}Ra	1.88E-08	8.57E-04	8.22E+00	0.00E+00	8.22E+00
^{224}Ra	2.04E-01	2.88E+00	6.08E+00	0.00E+00	9.17E+00
^{225}Ra	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{228}Ra	0.00E+00	5.09E-09	1.52E+00	0.00E+00	1.52E+00
^{225}Ac	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{227}Ac	1.88E-08	8.57E-04	8.22E+00	0.00E+00	8.22E+00
^{228}Ac	0.00E+00	5.09E-09	1.52E+00	0.00E+00	1.52E+00
^{227}Th	1.85E-08	8.45E-04	8.10E+00	0.00E+00	8.10E+00
^{228}Th	2.04E-01	2.88E+00	6.08E+00	0.00E+00	9.17E+00
^{229}Th	1.41E-04	1.97E-03	2.08E-01	0.00E+00	2.10E-01
^{230}Th	7.56E-06	1.46E-02	4.38E-02	0.00E+00	5.84E-02
^{231}Th	6.41E-03	8.94E-02	5.17E-03	0.00E+00	1.01E-01
^{232}Th	0.00E+00	5.87E-09	1.64E+00	0.00E+00	1.64E+00
^{234}Th	5.71E-02	7.97E-01	7.11E-05	0.00E+00	8.54E-01

Table 2.20 (continued)

Radionuclide	Alkaline waste (PUREX) Liquid (Ci)	Alkaline waste (PUREX) Sludge (Ci)	Acid waste (THOREX) Liquid (Ci)	Zeolite waste (Ion exchanger) Slurry (Ci)	Total (Ci)
^{231}Pa	4.06E-07	2.98E-04	1.52E+01	0.00E+00	1.52E+01
^{233}Pa	3.25E-06	2.31E+01	3.02E-01	0.00E+00	2.34E+01
^{234m}Pa	5.71E-02	7.97E-01	7.11E-05	0.00E+00	8.54E-01
^{232}U	3.04E-01	4.26E+00	2.66E+00	0.00E+00	7.23E+00
^{233}U	4.98E-01	6.94E+00	2.09E+00	0.00E+00	9.53E+00
^{234}U	2.81E-01	3.97E+00	2.21E-01	0.00E+00	4.47E+00
^{235}U	6.41E-03	8.94E-02	5.17E-03	0.00E+00	1.01E-01
^{236}U	1.91E-02	2.67E-01	9.80E-03	0.00E+00	2.96E-01
^{238}U	5.71E-02	7.97E-01	7.11E-05	0.00E+00	8.54E-01
^{236}Np	0.00E+00	9.35E+00	1.23E-01	0.00E+00	9.47E+00
^{237}Np	3.25E-06	2.31E+01	3.02E-01	0.00E+00	2.34E+01
^{239}Np	0.00E+00	3.39E+02	7.83E+00	0.00E+00	3.47E+02
^{236}Pu	6.56E-03	8.28E-01	1.09E-02	0.00E+00	8.46E-01
^{238}Pu	1.24E+02	7.82E+03	4.69E+02	0.00E+00	8.41E+03
^{239}Pu	2.54E+01	1.61E+03	1.54E+01	0.00E+00	1.65E+03
^{240}Pu	1.87E+01	1.18E+03	8.09E+00	0.00E+00	1.21E+03
^{241}Pu	1.26E+03	7.99E+04	7.36E+02	0.00E+00	8.19E+04
^{242}Pu	2.54E-02	1.61E+00	1.19E-02	0.00E+00	1.65E+00
^{241}Am	6.53E+00	5.32E+04	2.44E+02	0.00E+00	5.34E+04
^{242}Am	0.00E+00	2.89E+02	6.66E+00	0.00E+00	2.95E+02
^{242m}Am	0.00E+00	2.90E+02	6.70E+00	0.00E+00	2.97E+02
^{243}Am	0.00E+00	3.39E+02	7.83E+00	0.00E+00	3.47E+02
^{242}Cm	0.00E+00	2.39E+02	5.53E+00	0.00E+00	2.45E+02
^{243}Cm	0.00E+00	1.34E+02	2.18E-01	0.00E+00	1.34E+02
^{244}Cm	0.00E+00	7.63E+03	1.22E+01	0.00E+00	7.64E+03
^{245}Cm	0.00E+00	8.62E-01	2.00E-02	0.00E+00	8.82E-01
^{246}Cm	0.00E+00	8.97E-02	2.29E-03	0.00E+00	1.01E-01
Total	1.13E+07	1.30E+07	1.72E+06	1.86E+06	2.79E+07
Specific activity, Ci/L	6.5E+00	2.8E+02	3.4E+01	6.0E+01	1.5E+01

[a]Taken from ref. 4.
[b]Includes all radionuclides >0.1 Ci prior to year 3090.

ORNL-PHOTO 6294-90

Photo 3.1. An aerial view of the DOE Waste Isolation Pilot Plant (WIPP) facility at Carlsbad, New Mexico, May 1990. (Courtesy of Westinghouse Electric Corporation, Waste Isolation Pilot Plant Project Office, Carlsbad, New Mexico.)

3. TRANSURANIC WASTE

3.1 INTRODUCTION

The term "transuranic" refers to elements with an atomic number greater than 92. Transuranic (TRU) waste is contaminated with alpha-emitting radionuclides having atomic numbers greater than 92 and half-lives greater than 20 years, in concentrations greater than 100 nCi/g of waste at the time of assay.[1] This material results primarily from the reprocessing of plutonium-bearing reactor fuel and the fabrication of plutonium-bearing weapons. Some TRU-contaminated waste is also generated by environmental restoration activities, which are discussed in Chapter 6, and by fuel cycle D&D activities, which are discussed in Chapter 7. Most TRU waste is trash (e.g., rags, coveralls, rubber gloves, equipment, and tools) that has become slightly contaminated with transuranic elements during nuclear material processing operations.

Prior to 1970, all TRU-contaminated waste was buried at several DOE and commercial sites in pits and trenches and covered with soil. In 1970, the federal government concluded that TRU wastes should have greater confinement from the environment. Consequently, since 1970 these wastes have been stored so they can be easily retrieved.[2] Although a few daughter products have energetic gamma emissions, most of this waste can be handled with the shielding that is provided by the waste package and is classified as "contact-handled" TRU waste. Only about 2.4% of the retrievably stored, TRU-contaminated waste inventory contains enough beta, gamma, and neutron emitters (more than 200 mrem/h) to require remote handling; this waste is designated as "remote-handled" TRU waste.

Early burial practices were not governed by the current requirements for identification and segregation. Therefore, studies have been made of these disposal practices to estimate the amounts and nature of TRU-contaminated wastes and to assess certain long-term management options.[3]

A summary of the current inventory and projected accumulation at government storage sites of all buried, TRU-contaminated waste, as well as all retrievably stored waste from DOE activities, is given in Table 3.1. The locations of these sites are shown on the map in Fig. 3.1. DOE retrievably stored TRU waste from these sites, as well as newly generated TRU waste, will be shipped to, and emplaced in, the WIPP on a demonstration basis. The demonstration period is scheduled for up to 5 years, and if successful, disposal at WIPP will be continued until 2013.

Figure 3.2 identifies the points of origin and storage sites of DOE TRU waste. After WIPP opens, the newly generated TRU waste from some generators will be shipped to WIPP instead of to the interim storage sites. Figures 3.3 and 3.4, respectively, show the waste volumes and masses of TRU-contaminated waste (from DOE activities) that were buried at the principal government sites. Figures 3.5 and 3.6, respectively, show the certifiable TRU waste volumes and masses of elements (from DOE activities) that are presently being held in retrievable storage at DOE sites.

3.2 INVENTORIES

Prior to the AEC's directive[2] of March 1970, LLW containing TRU nuclides was disposed of by shallow-land burial at AEC and commercial sites. The estimated total volume and mass of contained TRU elements presently buried at AEC (now DOE) sites are given in Table 3.2 (based on refs. 4 and 5). Radioactivity has been estimated from historical emplacement records.

Over the years, some of the buried waste containers have been breached, and the surrounding soil has been contaminated. Also, in the early days at Hanford, ORNL, and Los Alamos, some liquid waste that contained TRU elements was spilled on, or drained to, the earth. It is very difficult to accurately determine the volume of contaminated soil and the mass of TRU elements in the soil. Current estimates are listed in Table 3.3, but further characterization will be needed.

In 1970, the AEC initiated a policy of retrievable storage for TRU waste. Each site packaged wastes containing concentrations greater than 10 nCi/g separately, so that they would be intact and readily retrievable for at least 20 years. Separate storage facilities were established, with each site selecting methods suited for local waste types and climate conditions. The currently reported TRU waste inventories are subject to uncertainty. In 1984, the control value was set at greater than 100 nCi/g.[6] In addition, nondestructive assay (NDA) methods were not available, until recently, to accurately and reliably

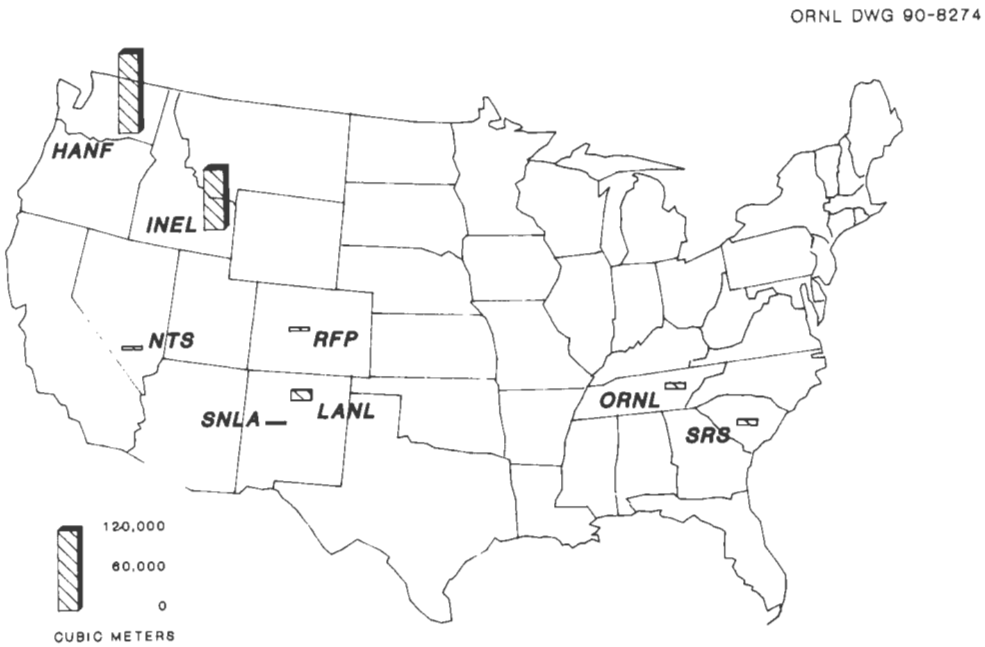
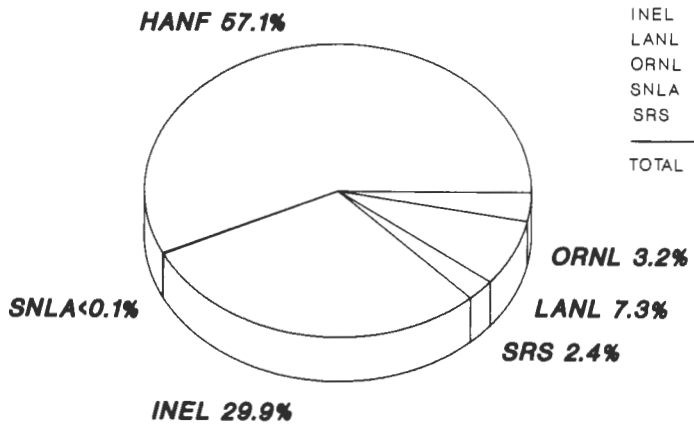


Fig. 3.1. Locations and total volumes of buried and stored DOE TRU waste through 1989.

Fig. 3.2. Points of origin and storage sites of DOE TRU waste.

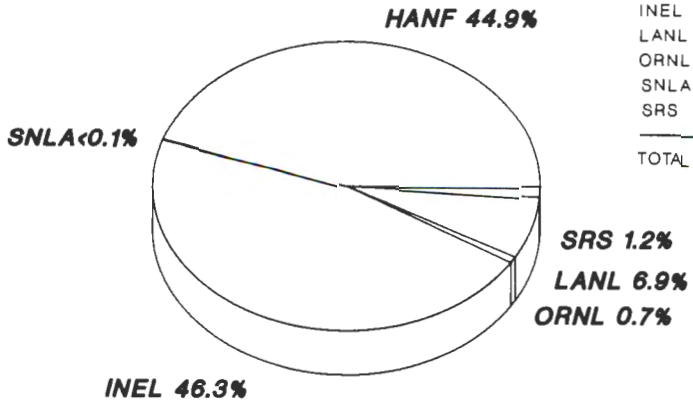
ORNL DWG 90-8276



SITE	CUBIC METERS
HANF	1.09E+05
INEL	5.71E+04
LANL	1.40E+04
ORNL	6.20E+03
SNLA	3.00E+00
SRS	4.53E+03
TOTAL	1.91E+05

Fig. 3.3. Total volume of buried DOE TRU waste through 1989.

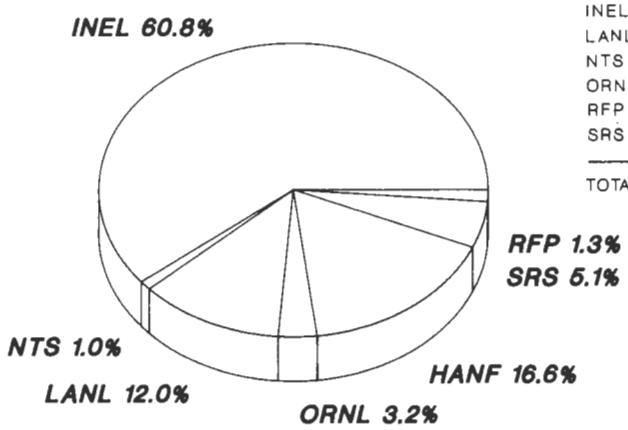
ORNL DWG 90-8277



SITE	KILOGRAMS
HANF	3.46E+02
INEL	3.57E+02
LANL	5.35E+01
ORNL	5.60E+00
SNLA	<1.00E+00
SRS	9.10E+00
TOTAL	7.71E+02

Fig. 3.4. Total mass of buried TRU elements in DOE TRU waste through 1989.

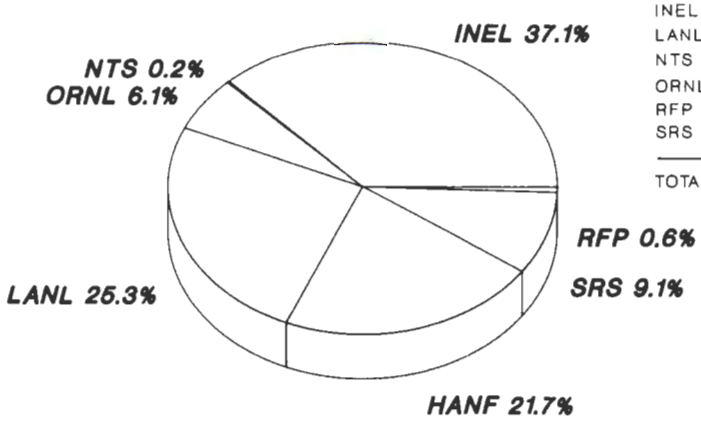
ORNL DWG 90-8278



SITE	CUBIC METERS
HANF	1.02E+04
INEL	3.74E+04
LANL	7.42E+03
NTS	6.06E+02
ORNL	1.97E+03
RFP	7.92E+02
SRS	3.14E+03
TOTAL	6.16E+04

Fig. 3.5. Total volume of retrievably stored DOE TRU waste through 1989.

ORNL DWG 90-8279



SITE	KILOGRAMS
HANF	4.76E+02
INEL	8.12E+02
LANL	5.54E+02
NTS	4.10E+00
ORNL	1.33E+02
RFP	1.24E+01
SRS	2.00E+02
TOTAL	2.19E+03

Fig. 3.6. Total mass of retrievably stored TRU elements in DOE TRU waste through 1989.

distinguish between containers whose contents are TRU waste and containers whose contents are LLW. Therefore, all the wastes generated at a facility that handled TRU materials were assumed to be TRU wastes (except at LANL, which had a multiple-energy gamma assay system in the mid-1970s). Nondestructive methods have now been developed and demonstrated to characterize packaged TRU wastes.[7] Most of the storage sites and sites generating large quantities of TRU-contaminated waste have installed nondestructive assay/nondestructive examination (NDA/NDE) systems and will segregate the LLW and TRU waste as part of their certification program. The utilization of these assay systems and the resulting segregation of LLW and TRU have led to a large reduction in the projected amount of TRU waste that will be available for shipment to WIPP. Table 3.4 reports the certification results as of December 31, 1989. Table 3.5 summarizes DOE site data on the volume, TRU elemental mass, and radioactivity for retrievably stored, certifiable TRU waste and waste managed as LLW, as of December 31, 1989. Estimates of the radioactivity of these wastes are based on emplacement records and a knowledge of the types of operations carried out at each generation site. Based on the sampling program now under way and the current definition of TRU waste, it is estimated that 38% (approximately 36,543 m^3) of the current inventory of retrievably stored waste will be designated as LLW. Those containers whose contents are declared to be LLW will be managed as such. The current TRU waste inventories within this document have been modified accordingly.

The ongoing review of historical waste storage records and the continuing characterization studies generate updated information that makes previously published data obsolete. Table 3.6 (based on refs. 4 and 8) has been prepared to provide continuity in IDB publications by showing revisions, corrections, and additions that have occurred in TRU waste inventories during the past year. The algebraic sum of these quantities and the previous year-end inventory gives the current inventory.

3.3 WASTE CHARACTERIZATION

3.3.1 Physical Composition

Through ongoing characterization studies, the DOE sites[4] have estimated that a major portion of the buried, retrievable, and newly generated TRU waste is composed of the physical species given in Table 3.7.

3.3.2 Isotopic Composition

Isotopic compositions are given in Table 3.8 for buried, contact-handled, and remote-handled waste at the DOE emplacement sites. Background knowledge of the operations carried out at each site and of the sources of off-site TRU waste was used in designating compositions when documented data were not available. Data on the compositions of both contact-handled and remote-handled TRU waste were available for all sites; however, composition data were not available for TRU waste buried at ORNL and portions of the waste buried at SRS. For making radioactivity and thermal power calculations, the composition of these buried TRU wastes was assumed to be the same as that of the rest of the contact-handled TRU waste on a site-specific basis. In Table 3.8, the percentage of waste in each "Mix" (composition mixture) is based on the total of the volume in storage plus the volume generated at the site through 2013.

Calculations of radioactivity and thermal power for the current and projected inventories of TRU waste at each storage site have been made using a simplified version of the ORIGEN2 computer program and the appropriate isotopic data.[4] Summaries of the total system current and projected volumes and mass inventories, as well as calculated radioactivity and thermal power, of all TRU wastes are given in Table 3.1, whereas Table 3.9 lists only the TRU waste data that have accumulated at each storage site through 1989. Radioactivity values (Tables 3.2 and 3.5) that are reported by the storage sites for the current year do not generally agree with the corresponding computed values in Tables 3.1 and 3.9, since the site data rely on values that were reported by individual waste generators at the time the waste was placed in storage and may not account for all of the radioactive decay, especially that from daughter products. Yearly improvements in site characterization methods will result in site data revisions until characterization is complete, at which time the differences between the reported and calculated radioactivities should be much smaller.

3.4 SHIPMENT AND DISPOSAL

It is the goal of DOE's Transuranic Waste Program to terminate interim storage and to achieve permanent disposal of DOE TRU waste.[9] In compliance with Public Law 96-164,[10] the WIPP project is being constructed "... as a defense activity of the DOE for the purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States."

The WIPP R&D facility will receive TRU waste to demonstrate its safe disposal on an experimental basis.[9] While the mining of the first waste panel (a measure of room storage) has been completed, additional storage panels will be mined as needed. Waste must be certified to meet the WIPP waste acceptance criteria prior to being accepted at WIPP for disposal. The waste acceptance criteria and associated quality assurance

requirements are specified in WIPP/DOE-069 and -120.[11,12] The initial shipments will be in support of the WIPP Test Phase plan. Several sites will be involved in these shipments which will include only contact-handled TRU waste. According to current plans, remote-handled TRU waste will be shipped to WIPP at a later date.

3.5 PROJECTIONS

The projected rates[4] at which TRU waste will be generated at various government facilities are given in Table 3.10, and the estimated physical composition of these newly generated wastes is given in Table 3.7. Projected TRU waste totals through 2013 are reported in Table 3.1. In addition, a small amount of TRU waste will be generated in environmental restoration activities under the Defense D&D Program and the SFMP, which are discussed in Sects. 6.4 and 6.5, respectively.

3.6 REFERENCES

1. U.S. Department of Energy, Radioactive Waste Management, DOE Order 5820.2A, Washington, D.C. (Sept. 26, 1988).

2. K. S. Hollingsworth, Policy Statement Regarding Solid Waste Burial, AEC Directive IAD No. 0511-21, Washington, D.C. (Mar. 20, 1970).

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4. M. H. McFadden, U.S. Department of Energy, Albuquerque Operations Office, WIPP Project Office, Carlsbad, New Mexico, memorandum to J. A. Klein, Oak Ridge National Laboratory, Oak Ridge, Tennessee, detailing TRU Waste Program's IDB submittal through December 31, 1989, dated July 26, 1990.

5. D. M. Lund, U.S. Department of Energy, Albuquerque Operations Office, Albuquerque, New Mexico, memorandum to J. A. Klein, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "TRU Waste Program's IDB Submittal through Dec. 31, 1986," dated Mar. 31, 1987.

6. U.S. Department of Energy, Radioactive Waste Management, DOE Order 5820.2, Washington, D.C. (Feb. 6, 1984).

7. F. J. Schultz et al., Neutron and Gamma Ray Nondestructive Examination of Contact-Handled Transuranic Waste at the ORNL TRU Waste Drum Assay Facility, ORNL-6103, Oak Ridge National Laboratory, Oak Ridge, Tennessee (March 1985).

8. U.S. Department of Energy, Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 5, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1989).

9. U.S. Department of Energy, Long Range Master Plan for Defense Transuranic Waste Program, DOE/WIPP 88-028, Carlsbad, New Mexico (December 1988).

10. U.S. Congress, Department of Energy National Security and Military Application of Nuclear Energy Authorization Act of 1980, Pub. L. 96-164 (1980).

11. U.S. Department of Energy, TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant, WIPP/DOE-069, Rev. 3, Carlsbad, New Mexico (January 1989).

12. U.S. Department of Energy, Quality Assurance Requirements for Certification of TRU Waste for Shipment to the WIPP, WIPP/DOE-120, Rev. 2, Carlsbad, New Mexico (August 1988).

Table 3.1. Total system inventories, projections, and characteristics of all buried and stored DOE TRU waste in 5-year increments[a]

End of calendar year	Volume (m^3)		Mass[b] (kg)		Radioactivity[c] (10^3 Ci)		Thermal power[c] (10^3 W)	
	Annual rate[d]	Accumulation	Annual rate[d]	Accumulation	Annual rate[d]	Accumulation	Annual rate[d]	Accumulation
				Buried[e]				
1989	0.0	190,837.0	0.0	771.2	0.0	211.9	0.0	3.3
1990	0.0	190,837.0	0.0	771.2	0.0	206.8	0.0	3.3
1995	0.0	190,837.0	0.0	771.2	0.0	184.5	0.0	3.3
2000	0.0	190,837.0	0.0	771.2	0.0	166.9	0.0	3.3
2005	0.0	190,837.0	0.0	771.2	0.0	152.8	0.0	3.3
2010	0.0	190,837.0	0.0	771.2	0.0	141.6	0.0	3.3
2015	0.0	190,837.0	0.0	771.2	0.0	132.7	0.0	3.3
2020	0.0	190,837.0	0.0	771.2	0.0	125.5	0.0	3.2
				Stored, contact-handled[f]				
1989	2,187.3	60,057.0	53.7	2,071.9	106.2	1,179.6	3.1	27.2
1990	1,933.4	61,990.4	147.8	2,219.7	221.0	1,379.5	5.9	33.0
1995	1,933.4	71,657.4	147.8	2,958.6	221.0	2,344.3	5.9	61.3
2000	1,933.4	81,324.4	147.8	3,697.5	221.0	3,256.1	5.9	88.6
2005	1,933.4	90,991.4	147.8	4,436.3	221.0	4,120.8	5.9	115.0
2010	1,933.4	100,658.4	147.8	5,175.1	221.0	4,943.2	5.9	140.4
2013	1,933.4	106,458.6	147.8	5,618.3	221.0	5,418.1	5.9	155.2
2015[g]								
				Stored, remote-handled[f]				
1989	3.0	1,501.9	0.0	119.4	0.0	2,486.0	0.0	8.4
1990	160.1	1,662.0	0.4	119.6	0.5	2,427.9	0.0	8.2
1995	160.1	2,462.5	0.4	120.5	0.5	2,159.5	0.0	7.3
2000	160.1	3,263.0	0.4	121.6	0.5	1,921.5	0.0	6.5
2005	160.1	4,063.5	0.4	122.7	0.5	1,710.4	0.0	5.8
2010	160.1	4,864.0	0.4	124.0	0.5	1,523.1	0.0	5.2
2013	160.1	5,344.3	0.4	124.7	0.5	1,421.0	0.0	4.9
2015[g]								
				Total stored[h]				
1989	2,190.3	61,558.9	53.7	2,191.3	106.2	3,665.5	3.1	35.6
1990	2,084.5	63,643.4	148.2	2,339.3	221.5	3,807.4	5.9	41.3
1995	2,084.5	74,065.9	148.2	3,079.1	221.5	4,503.8	5.9	68.6
2000	2,084.5	84,488.4	148.2	3,819.1	221.5	5,177.6	5.9	95.1
2005	2,084.5	94,910.9	148.2	4,559.0	221.5	5,831.2	5.9	120.8
2010	2,084.5	105,333.4	148.2	5,299.1	221.5	6,466.3	5.9	145.6
2013	2,084.5	111,586.9	148.2	5,743.0	221.5	6,839.1	5.9	160.1
2015[g]								

[a]Assembled from data provided in ref. 4 and Tables 3.2, 3.5, 3.8, and 3.10.

[b]Mass of TRU nuclides.

[c]Values were calculated using the estimated isotopic compositions for TRU waste at the several sites. See Sect. 3.3 for details. Calculations based on last burial date and on an average 10-year storage.

[d]Annual rate is for the indicated year only (not an average for the 5-year period).

[e]No TRU waste was buried after 1978.

[f]Certified TRU waste. Excludes waste managed as LLW. See Table 3.5.

[g]The destination of TRU waste after 2013 will not be defined until 2002.

[h]The total radioactivity and thermal power columns do not include values for Hanford's projected stored, remote-handled waste. The isotopic composition of this waste is unknown.

Table 3.2. Inventories and characteristics of DOE buried TRU waste through 1989

Burial site	Values reported by storage site as of December 31, 1989[a]		
	Volume (m^3)	Mass of TRU nuclides (kg)	TRU alpha radioactivity[b] (Ci)
HANF[c]	109,000	346	29,200
INEL	57,100	357	73,267
LANL	14,000	53.5	9,230
ORNL	6,200	5.6	270[d]
SNLA[e]	3	<<1	1
SRS	4,534	9.1	9,831
Total	190,837	771.2	121,799

[a]Data from ref. 4.
[b]As reported by storage sites. Does not include beta and gamma radioactivity or radiation from decay products.
[c]Includes soils mixed with buried waste.
[d]Total of all radioactivity.
[e]Data from ref. 5.

Table 3.3. Inventories and characteristics of soil contaminated with DOE TRU waste through 1989[a]

Site	Volume (m^3)	Mass of TRU nuclides (kg)	TRU alpha radioactivity (Ci)
HANF	31,960	190.2	16,706
INEL	56,000-156,000	b	b
LANL	1,140	b	b
MOUND	300-1,000	0.009-0.029	150-526
ORNL	13,000-61,000[c]	b	b
SRS	38,000	b	b
Total	140,400-289,100	b	b

[a]Data from ref. 4.
[b]Reported as unknown.
[c]If soil containing TRU waste can be isolated from 1,600,000 m^3 of soil containing TRU waste and LLW. Total also includes 1,000 m^3 of contaminated soil around tanks.

Table 3.4. Certification status of historical, retrievable DOE TRU waste at each storage site through 1989[a]

Storage site	Certification status of containers, vol % of total					
	Certifiable without processing[b,c]	Certifiable with current processing[c,d]	Certifiable with future processing[c,e]	Managed as LLW[c,f]	Not certifiable with existing technology[c,g]	Ship to another site for processing[c]
			Contact-handled			
HANF	1	0	64	35	<1	<<1
INEL	43	9	6	42	0	0
LANL	51	32	10	4	3	0
NTS	90	7	0	0	3	0
ORNL	0	0	97	3	0	0
SRS	0	0	46	54	0	0
			Remote-handled			
HANF	0	0	100	0	0	<<1
INEL	0	0	52	37	10	1
LANL	39	0	0	0	61	0
ORNL	0	0	~100	0	<<1	0

[a]Data from ref. 4.
[b]TRU waste that can be certified at the point of generation with no further processing.
[c]Percentage depicts projected waste disposition.
[d]TRU waste that is certifiable after processing with existing equipment and facilities.
[e]Technology for TRU waste disposal that is identified but awaits facility funding prior to 2013.
[f]Waste that is stored as TRU waste but falls below the 100-nCi/g alpha activity level.
[g]Waste considered not to be certifiable with existing technology at the site identified.

Table 3.5. Inventories and characteristics of retrievable DOE TRU waste at each storage site through 1989[a]

Site	Certifiable TRU waste		Managed as LLW		Total		
	Volume (m^3)	Mass of TRU nuclides (kg)	Volume (m^3)	Mass of TRU nuclides (kg)	Containerized volume[b] (m^3)	Mass of TRU nuclides[b] (kg)	Alpha radioactivity[b,c] (Ci)
				Contact-handled			
HANF	10,041	465	5,289	0	15,330	465	53,707
INEL	37,420	811.1	27,335	11.6	64,755	822.7	207,386
LANL	7,393.1	552.4	272.2	0.2	7,665.3	552.6	187,225
NTS	606.3	4.1	0	0	606.3	4.1	712
ORNL	661.6	26.6	17.7	<<0.1	679.3	26.6	17,520
RFP[d]	792	12.4	0	0	792	12.4	410
SRS	3,143	200.3	3,629	2.6	6,772	202.9	659,524
Total	60,057	2,071.9	36,542.9	14.4	96,599.9	2,086.3	1,126,484
				Remote-handled			
HANF	137	11	0	0	137	11	1,476
INEL	29.5	0.41	21	0.01	50.5[e]	0.42	39.9
LANL	28.4	1.8	0	0	28.4	1.8	150
ORNL	1,307	106.2	0	0	1,307[f]	106.2	2,619[g]
Total	1,501.9	119.41	21	0.01	1,522.9	119.42	4,284.9

[a]Data from ref. 4.
[b]Includes waste certified as TRU waste plus stored waste that is to be managed as LLW.
[c]As reported by storage site. Does not include beta and gamma radioactivity or radiation from decay products.
[d]Temporary on-site storage at RFP.
[e]INEL data include RH waste to be shipped to ORNL-WHPP for processing but do not include 9 canisters that will be returned to ICPP.
[f]This is total waste volume, not container volume.

Table 3.6. Revisions and changes in historical inventories of DOE TRU waste from previous IDB report[a]

Site	Contact-handled: Value as of Dec. 31, 1988[b,c]	Contact-handled: Revisions and/or corrections to 1988 data[c]	Contact-handled: Quantity added during 1989	Contact-handled: Value as of Dec. 31, 1989	Remote-handled: Value as of Dec. 31, 1988[b,c]	Remote-handled: Revisions and/or corrections to 1988 data[c]	Remote-handled: Quantity added during 1989	Remote-handled: Value as of Dec. 31, 1989
				Total volume, m^3				
HANF	9,876	+21	144	10,041	137	0	0	137
INEL[d]	36,640	-92	872	37,420	32.8	-3.3	0	29.5
LANL[e]	7,179.4	46.5	167.2	7,393.1	11.1	+17.3	0	28.4
NTS[f]	596	+10.3	0	606.3	0	0	0	0
ORNL	607.5	0	54.1	661.6	1,304[g]	0	3	1,307
RFP[h]			792	792				
SRS	3,297	-312	158	3,143	0	0	0	0
Total	58,195.9	-326.2	2,187.3	60,057	1,484.9	+14	3	1,501.9
				Mass of TRU elements, kg				
HANF	436	+25	4	465	11	0	0	11
INEL[d]	736.2	+59.6	15.3	811.1	0.5	-0.09	0	0.41
LANL	541.5	-3.2	14.1	552.4	1.8	0	0	1.8
NTS	4.1	0	0	4.1	0	0	0	0
ORNL	26.6	0	0.01	26.61	106.2	0	~0	106.2
RFP[h]			12.4	12.4				
SRS	192.4	0	7.9	200.3	0	0	0	0
Total	1,936.8	+81.4	53.71	2,071.91	119.5	-0.09	~0	119.41
				Alpha radioactivity, Ci				
HANF	35,830	+17,475	402	53,707	1,476	0	0	1,476
INEL[d]	260,156	-54,158	1,388	207,386	47	-7.1	0	39.9
LANL	187,717	-3,334	2,842	187,225	63	+87	0	150
NTS	705	7	0	712	0	0	0	0
ORNL	17,505	0	15	17,520	2,619	0	~0	2,619
RFP[h]			410	410				
SRS	653,165	+19	6,340	659,524	0	0	0	0
Total	1,155,078	-39,991	11,397	1,126,484	4,205	+79.9	~0	4,284.9
				Volume of buried TRU waste, m^3				
HANF	109,000	0	0	109,000				
INEL	57,100	0	0	57,100				
LANL	14,000	0	0	14,000				
ORNL	6,200	0	0	6,200				
SNLA	3	0	0	3				
SRS	4,534	0	0	4,534				
Total	190,837	0	0	190,837				

Table 3.6 (continued)

Site	Contact-handled: Value as of Dec. 31, 1988[b,c]	Contact-handled: Revisions and/or corrections to 1988 data[c]	Contact-handled: Quantity added during 1989	Contact-handled: Value as of Dec. 31, 1989	Remote-handled: Value as of Dec. 31, 1988[b,c]	Remote-handled: Revisions and/or corrections to 1988 data[c]	Remote-handled: Quantity added during 1989	Remote-handled: Value as of Dec. 31, 1989
			Mass of TRU elements in buried TRU waste, kg					
HANF	346	0	0	346				
INEL	357	0	0	357				
LANL	53.5	0	0	53.5				
ORNL	5.6	0	0	5.6				
SNLA	0	0	0	0				
SRS	9.1	0	0	9.1				
Total	771.2	0	0	771.2				
			Alpha radioactivity in buried TRU waste, Ci					
HANF	29,200	0	0	29,200				
INEL	73,267	0	0	73,267				
LANL	9,230	0	0	9,230				
ORNL	270	0	0	270				
SNLA	1	0	0	1				
SRS	9,831	0	0	9,831				
Total	121,799	0	0	121,799				

[a]Data from ref. 4.
[b]Data from ref. 8.
[c]The 1989 IDB did not include special-case waste. The special-case waste has been incorporated in the 1990 report.
[d]INEL developed computer programs to generate the data for these reports. Consequently, previous inconsistencies have been corrected.
[e]Correction to special-case waste values.
[f]Minor revisions to parameters.
[g]Value reported is volume of waste only, not container volume.
[h]Temporary on-site storage at RFP beginning in 1989.

Table 3.7. Estimated physical composition of retrievably stored, newly generated, and buried TRU waste at DOE sites[a]

Waste type	Waste composition, vol %				
	Contact-handled		Remote-handled		
	RSW[b]	NGW[c]	RSW[b]	NGW[c]	Buried
ANL-E					
Absorbed liquids or sludges		36			
Combustibles		32		50	
Glass, metal, or similar noncombustibles		32		50	
HANF					
Absorbed liquids or sludges					1
Combustibles	43	33.8	66	2	43
Concreted or cemented sludge	6	21.6	2		
Dirt, gravel, or asphalt	3	15.8			3
Filters or filter media		8.2		10	1
Glass, metal, or similar noncombustibles	48	20.6	32	88	48
Other					4
INEL					
Absorbed liquids or sludges	12				23.4
Combustibles	25	43.3	8	8	31.8
Concreted or cemented sludges	13	15.8			3.9
Dirt, gravel, or asphalt					6.7
Filters or filter media	5	0.5	11	11.2	1.3
Glass, metal, or similar noncombustibles	35	14.6	80[d]	80[d]	10.5
Other	10	25.8	1	0.8	22.4
LANL					
Absorbed liquids or sludges	22	1			4
Combustibles	13	40.5	50	50	7
Concreted or cemented sludges	30	18			44
Dirt, gravel, or asphalt		1			30
Filters or filter media	5	2.5			2
Glass, metal, or similar noncombustibles	30	38	50	50	13
LLNL					
Combustibles		73			
Concreted or cemented sludges		1			
Filters or filter media		7			
Glass, metal, or similar noncombustibles		15			
Other		4			
MOUND					
Combustibles		1			
Concreted or cemented sludges		1			
Dirt, gravel, or asphalt		89			
Glass, metal, or similar noncombustibles		9			
NTS					
Combustibles	51.5				
Concreted or cemented sludges	1.0				
Glass, metal, or similar noncombustibles	47.5				

Table 3.7 (continued)

Waste type	Waste composition, vol %				
	Contact-handled		Remote-handled		
	RSW[b]	NGW[c]	RSW[b]	NGW[c]	Buried
ORNL					
Absorbed liquids or sludges			64		
Combustibles	59	12	20		Unknown
Dirt, gravel, or asphalt	1	1	1		
Filters or filter media	5	5	14	1	
Glass, metal, or similar noncombustibles	35	82	1	97	
Other				2	
RFP					
Combustibles		15.5			
Concreted or cemented sludges		36.3			
Dirt, gravel, or asphalt		0.7			
Filters or filter media		0.7			
Glass, metal, or similar noncombustibles		41.3			
Other		5.5			
SRS[e]					
Absorbed liquids or sludges	e	2.0			e
Combustibles	e	64.0			e
Filters or filter media	e	5.0			e
Glass, metal, or similar noncombustibles	e	27.5			e
Other	e	1.5			e

[a]Data from ref. 4.
[b]Retrievably stored waste (RSW). Vol % is best estimate of waste after processing and certification.
[c]Newly generated waste (NGW).
[d]This is alpha hot-cell waste.
[e]For SRS, composition of contact-handled RSW is unknown. The estimated characterization before processing is 30% noncombustible, 70% combustible. Composition of the buried waste is also unknown.

Table 3.8. Calculated isotopic composition (wt %) of buried and retrievably stored TRU waste for each site[a]

Site	Major isotopes[b]	Retrievably stored and newly generated wastes, wt %										Buried
		Contact-handled						Remote-handled				
		Mix-1[c]	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10	Mix-11
ANL-E[d]	^{235}U	–	–	–	–	–	–	56.0	–	–	–	–
	^{239}Pu	87	85	–	–	–	–	40.0	–	–	–	–
	^{240}Pu	11	8	–	–	–	–	4.0	–	–	–	–
	^{241}Am	1	1	–	–	–	–	–	–	–	–	–
	^{237}Np	–	5	–	–	–	–	–	–	–	–	–
	^{241}Pu	1	1	–	–	–	–	–	–	–	–	–
	MFP[e]	–	–	–	–	–	–	<1.0	–	–	–	–
HANF[f,g]	^{239}Pu	2.2	–	–	–	–	–	2.2	4.8	–	–	2.2
	^{240}Pu	0.1	–	–	–	–	–	0.1	0.7	–	–	0.1
	^{241}Pu	–	–	–	–	–	–	–	0.1	–	–	–
	^{232}Th	3.1	–	–	–	–	–	3.1	16.0	–	–	3.1
	U depleted	72.8	–	–	–	–	–	72.8	21.6	–	–	72.8
	U enriched	1.8	–	–	–	–	–	1.8	54.3	–	–	1.8
	U normal	19.9	–	–	–	–	–	19.9	2.4	–	–	19.9
	Other	0.1	–	–	–	–	–	0.1	0.1	–	–	0.1
INEL[h]	^{241}Am	0.08	5.00	1.7	–	–	–	–	–	–	–	Trace
	^{238}Pu	Trace	–	Trace	–	–	–	–	–	–	–	–
	^{239}Pu	92.99	80.00	91.0	Trace	–	–	5.00	1.35	–	–	Trace
	^{240}Pu	5.80	10.00	5.7	–	–	–	1.00	0.15	–	–	Trace
	^{241}Pu	0.40	–	0.3	–	–	–	–	–	–	–	Trace
	^{242}Pu	0.03	–	Trace	–	–	–	–	–	–	–	Trace
	^{232}Th	–	–	–	95.00	–	–	–	–	–	–	–
	^{233}U	–	–	–	5.00	–	–	–	–	–	–	–
	^{235}U	–	–	0.6	–	–	–	38.20	39.40	–	–	0.1
	^{238}U	–	–	–	–	–	–	55.20	59.10	–	–	99.8
	MFP	–	–	–	–	–	–	0.60	–	i	j	–
	Other	0.70	5.00	–	–	–	–	–	–	–	–	0.1[k]
LANL[l]	^{235}U	1.9	–	–	–	–	–	47	47	–	–	–
	^{238}U	67.1	–	–	–	–	–	28	28	–	–	5.0
	^{238}Pu	0.5	0.5	1.2	0.5	–	–	–	–	–	–	0.01
	^{239}Pu	30.5	21.5	98.8	93	100	–	22.7	22.7	–	–	91
	^{240}Pu	–	–	–	–	–	–	2.1	2.1	–	–	–
	^{241}Pu	–	–	–	–	–	–	0.2	0.2	–	–	–
	^{241}Am	0.2	78	–	6.5	–	–	–	–	–	–	3.3
	MFP	–	Trace	–	–	–	–	m	n	–	–	–
	Other	–	–	–	–	–	–	–	–	–	–	0.69

Table 3.8 (continued)

Site	Major isotopes[b]	Retrievably stored and newly generated wastes, wt %										
		Contact-handled						Remote-handled				Buried
		Mix-1[c]	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10	Mix-11
LLNL[o]	^{238}Pu	0.016	0.066	0.011	0.055	0.042	-	-	-	-	-	-
	^{239}Pu	93.464	78.964	73.657	63.557	86.149	-	-	-	-	-	-
	^{240}Pu	5.900	17.427	24.896	14.027	11.714	-	-	-	-	-	-
	^{241}Pu	0.381	1.180	0.424	0.950	0.784	-	-	-	-	-	-
	^{242}Pu	0.040	0.432	0.018	0.347	0.237	-	-	-	-	-	-
	^{241}Am	0.202	1.942	0.994	21.073	1.079	-	-	-	-	-	-
Mound[p]	^{238}Pu	79.894	-	-	-	-	-	-	-	-	-	-
	^{239}Pu	17.1	-	-	-	-	-	-	-	-	-	-
	^{240}Pu	3.0	-	-	-	-	-	-	-	-	-	-
	^{241}Pu	0.006	-	-	-	-	-	-	-	-	-	-
NTS[q]	^{238}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{239}Pu	93.55	-	-	-	-	-	-	-	-	-	-
	^{240}Pu	5.89	-	-	-	-	-	-	-	-	-	-
	^{241}Pu	0.54	-	-	-	-	-	-	-	-	-	-
	^{242}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{241}Am	Trace	-	-	-	-	-	-	-	-	-	-
ORNL[r]	^{233}U	67.34	6.13	-	-	-	-	-	94.57	52.55	-	-
	^{235}U	11.95	2.99	-	-	-	-	-	-	-	-	-
	^{238}U	-	7.69	-	-	-	-	-	-	-	-	-
	^{238}Pu	-	4.58	-	-	-	-	-	-	-	-	-
	^{239}Pu	20.71	42.44	99.98	-	-	-	98.77	2.57	29.99	-	-
	^{241}Am	-	1.68	-	-	-	-	Trace	2.11	-	-	-
	^{244}Cm	-	0.96	Trace	-	-	-	Trace	0.75	Trace	-	-
	^{252}Cf	-	0.15	Trace	-	-	-	Trace	-	-	-	-
	^{137}Cs	-	-	-	-	-	-	-	Trace	0.95	-	-
	^{90}Sr	-	-	-	-	-	-	-	-	15.18	-	-
	^{152}Eu	-	-	-	-	-	-	-	-	Trace	-	-
	^{154}Eu	-	-	-	-	-	-	-	-	Trace	-	-
	^{237}Np	-	13.03	-	-	-	-	-	-	-	-	-
	^{240}Pu	-	15.42	-	-	-	-	-	-	-	-	-
	^{241}Pu	-	3.78	-	-	-	-	-	-	-	-	-
	Other	-	1.15	0.02	-	-	-	1.23	-	1.33	-	-
RFP[s]	^{238}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{239}Pu	91.0	-	-	-	-	-	-	-	-	-	-
	^{240}Pu	5.7	-	-	-	-	-	-	-	-	-	-
	^{241}Pu	0.3	-	-	-	-	-	-	-	-	-	-
	^{242}Pu	Trace	-	-	-	-	-	-	-	-	-	-
	^{241}Am	1.7	-	-	-	-	-	-	-	-	-	-
	^{235}U	0.6	-	-	-	-	-	-	-	-	-	-

Table 3.8 (continued)

Site	Major isotopes[b]	Retrievably stored and newly generated wastes, wt %										
		Contact-handled						Remote-handled				Buried
		Mix-1[c]	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10	Mix-11
SRS[t]	^{238}Pu	0.02	83.7	80.4	-	-	-	-	-	-	-	-
	^{239}Pu	93.18	14.0	16.2	-	-	-	-	-	-	-	-
	^{240}Pu	6.0	2.0	2.5	-	-	-	-	-	-	-	-
	^{241}Pu	0.5	0.3	0.7	-	-	-	-	-	-	-	-
	^{242}Pu	-	-	0.2	-	-	-	-	-	-	-	-
	^{241}Am	0.3	-	-	-	100	-	-	-	-	-	-
	^{237}Np	-	-	-	100	-	-	-	-	-	-	-
	^{244}Cm	-	-	-	-	-	100	-	-	-	-	-

[a]Data from ref. 4.

[b]Isotopes listed are those that are either >1%, by weight, or >1%, by activity, of the total.

[c]The mixes represent major waste stream composition variations.

[d]At ANL-E, 40 vol % of the contact-handled TRU waste is Mix-1, 60 vol % is Mix-2, and 100 vol % of the remote-handled TRU waste is Mix-7.

[e]Assumed ^{137}Cs because it is the longest-lived major isotope in Mixed Fission Product (MFP). Mix-7 is ^{137}Cs, 99.0 activity % (A/O); and ^{239}Pu, 1.0 A/O.

[f]At HANF, 100 vol % of the contact-handled TRU waste is Mix-1, 3 vol % of the remote-handled TRU waste is Mix-7, 1 vol % is Mix-8, and 96 vol % is Mix-9 (the composition of Mix-9 is unknown), and 100 vol % of the TRU-contaminated buried waste is Mix-11.

[g]HANF reported isotopic composition of uranium as U depleted, U enriched, and U normal. For radionuclide decay calculations, the data were converted to ^{235}U and ^{238}U by assuming 99.5%, 97.0%, and 99.3% ^{238}U, respectively.

[h]At INEL, 85 vol % of the contact-handled TRU waste is Mix-1, 3 vol % is Mix-2, 11 vol % is Mix-3, and 1 vol % is Mix-4; 29 vol % of the remote-handled TRU waste is Mix-7, 3 vol % is Mix-8, 27 vol % is Mix-9, and 41 vol % is Mix-10. Mix-7 is ^{239}Pu, 3.0 A/O; ^{240}Pu, 2.0 A/O; and MFP, 95.0 A/O. ^{137}Cs chosen because it is the longest-lived isotope in MFP. 100 vol % of the TRU-contaminated buried waste is Mix-11.

[i]Mix-9 is ^{144}Ce, 49.8 A/O; ^{134}Cs, 10 A/O; ^{137}Cs, 19.9 A/O; ^{54}Mn, 0.1 A/O; ^{239}Pu, 0.2 A/O; and ^{90}Sr, 20 A/O.

[j]Mix-10 is ^{137}Cs, 0.9 A/O; ^{239}Pu, trace; ^{90}Sr, 1 A/O; ^{58}Co, 35.1 A/O; ^{60}Co, 7.1 A/O; ^{51}Cr, 0.9 A/O; ^{59}Fe, 0.9 A/O; and ^{54}Mn, 54.1 A/O.

[k]The other in Mix-11 is ^{241}Am, 19 A/O; ^{239}Pu, 8 A/O; ^{240}Pu, 2 A/O; ^{241}Pu, 70 A/O; and ^{242}Pu, 1 A/O.

[l]At LANL, 37 vol % of the contact-handled TRU waste is Mix-1, 11 vol % is Mix-2, 7 vol % is Mix-3, 44 vol % is Mix-4, and 2 vol % is Mix-5; 79 vol % of the remote-handled TRU waste is Mix-7, and 21 vol % is Mix-8. Also, 100 vol % of the TRU-contaminated buried waste is Mix-11. Mix-2 contains trace wt % MFP but 10.7 A/O MFP.

[m]Trace by wt %, 85% by activity.

[n]Trace by wt %, 95% by activity.

[o]At LLNL, 93.7 vol % of the contact-handled TRU waste is Mix-1, 1 vol % is Mix-2, 3 vol % is Mix-3, 2 vol % is Mix-4, and 0.3 vol % is Mix-5.

[p]At MOUND, 100 vol % of the contact-handled TRU waste is Mix-1.

[q]At NTS, 100 vol % of the contact-handled TRU waste is Mix-1.

[r]At ORNL, 27 vol % of the contact-handled TRU waste is Mix-1, 37 vol % is Mix-2, and 36 vol % is Mix-3; 28 vol % of the remote-handled TRU waste is Mix-7, 6 vol % is Mix-8, and 66 vol % is Mix-9. No information available on buried waste at ORNL.

[s]At RFP, 100 vol % of the contact-handled TRU waste is Mix-1. Weight % totals less than 100% due to traces and round off.

[t]At SRS, 55.6 vol % of the contact-handled TRU waste is Mix-1, 30.8 vol % is Mix-2, 3.3 vol % is Mix-3, 9.4 vol % is Mix-4, 0.5 vol % is Mix-5, and 0.2 vol % is Mix-6. No information available on buried waste at SRS.

Table 3.9. Volume, mass, radioactivity, and thermal power of DOE TRU waste at each burial and storage site through 1989[a]

Site	Volume (m^3)		Mass[b] (kg)		Radioactivity (10^3 Ci)	Thermal power (10^3 W)
	1989 rate	Accumulation	1989 rate	Accumulation	Accumulation	Accumulation
			Buried[c]			
HANF	0.0	109,000.0	0.0	346.0	82.6	0.9
INEL	0.0	57,100.0	0.0	357.0	78.7	0.9
LANL	0.0	14,000.0	0.0	53.5	9.1	0.3
ORNL	0.0	6,200.0	0.0	5.6	6.0	0.1
SNLA	0.0	3.0	0.0	0.0	0.0	0.0
SRS	0.0	4,534.0	0.0	9.1	35.5	1.2
Total	0.0	190,837.0	0.0	771.2	211.9	3.4
			Stored, contact handled[d,e]			
HANF	144	10,041.0	4	465.0	141.9	1.1
INEL	872	37,420.0	15.3	811.1	378.7	7.1
LANL	167.2	7,393.1	14.1	552.4	58.2	1.9
NTS	0	606.3	0	4.1	1.8	0.0
ORNL	54.1	661.6	0.01	26.6	40.3	0.5
RFP	792.0	792.0	12.4	12.4	5.5	0.1
SRS	158	3,143.0	7.9	200.3	553.2	16.5
Total	2,187.3	60,057.0	53.7	2,071.9	1,179.6	27.2
			Stored, remote handled[d,e]			
HANF	0	137.0	0	11.0	13.2	0.0
INEL	0	29.5	0	0.4	0.1	0.0
LANL	0	28.4	0	1.8	0.6	0.0
ORNL	3.0	1,307.0	~0	106.2	2,472.1	8.3
Total	3.0	1,501.9	~0	119.4	2,486.0	8.3

[a]Assembled from data provided in ref. 4 and Tables 3.2, 3.5, and 3.8.
[b]Values were calculated using the estimated isotopic compositions for TRU waste at the several sites given in ref. 4 and Table 3.8. See Sect. 3.3 for details.
[c]Radioactive decay calculations based on last burial date. No TRU waste was buried after 1978.
[d]Certified TRU waste. Excludes waste managed as LLW. See Table 3.5.
[e]Radioactive decay calculations based on an averaged 10-year storage.

Table 3.10. Projected average annual volume, mass, activity, and certification levels of TRU waste generated during 1990–2013[a]

Sites	Average annual container volume (m^3)[b]	Average annual TRU nuclide mass (kg)	Average annual alpha radioactivity (Ci)	Projected TRU waste, vol % of total: Certifiable with processing[b,c]	Certifiable with future processing[b,d]	Special case
			Contact-handled			
Storage[e]						
HANF	39.3	2.1[f]	176.7[f]	52	48	
INEL[g]	194.4	31.5	48.8	100	0	
LANL	200.0	41.0	19,900.0	100	0	
ORNL	25.0	0.9	580.0	0	100	
SRS	699.5	61.7	123,105.0	65	35	
Generation[h]						
ANL-E	7.5	0.4	29.6	100	0	
LLNL	50.3	0.5	105	86	0	14
Mound	39.4	0.005	93	100	0	
RFP	678	10.6	2,610	100	0	
Subtotal	1,933.4	148.7	146,648.1			
			Remote-handled			
Storage[e]						
HANF	147.3[i]	Unknown	Unknown	0	100	
INEL[j]	3.2	0.26	23.3	83	0	17
LANL[k]	0.2	<<0.01	<0.1	100	0	
ORNL	6.0	0.01	8.5	0	100	
Generation[h]						
ANL-E	3.4	0.12	9	100	0	
Subtotal	160.1	0.40	40.9			
Total	2,093.5	149.1	146,689			

[a]Data from ref. 4.
[b]Volumes included are only those associated with alpha activity greater than 100 nCi/g.
[c]Waste is certifiable after processing with existing equipment and facilities.
[d]Technology for waste certification is identified but awaits facility funding prior to 2013.
[e]These sites have been designated as TRU waste storage sites. Some newly generated waste may be shipped directly to WIPP in the future. The "vol % of total" columns reflect combined newly generated and retrievably stored certifiable TRU waste.
[f]These values are determined from 40% of the waste volume; the remaining waste volume has not been characterized.
[g]Summary of CH contributions from INEL operations.
[h]These sites generate but do not store TRU waste. Their waste may be sent to a designated site (HANF, INEL, LANL, NTS, ORNL, or SRS) or directly to WIPP.
[i]Does **not** include a total of 34,000 m^3 of uncharacterized waste which will probably be RH-TRU.
[j]Summary of RH contributions from ANL-W and ICPP.
[k]Waste generation projected for 1990 and 1991 only (5.4 m^3 total).

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Photo 4.1. Y-12 Plant DOE LLW being loaded into a radioactivity counter prior to ORNL Waste Management Technology Center (WMTC) demonstration burn in the Scientific Ecology Group (SEG) Incinerator at Oak Ridge, Tennessee. (Courtesy of Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee.)

4. LOW-LEVEL WASTE

4.1 INTRODUCTION

As used in this chapter, LLW means those radioactive wastes containing source, special nuclear, or by-product materials that are acceptable for disposal in a land disposal facility. This definition is the same as that in 10 CFR 61.2, which specifies that LLW is radioactive waste not classified as HLW, TRU waste, spent nuclear fuel, or by-product material specified as uranium or thorium tailings and waste. The nuclear accelerator-generated radioactive materials (NARM) and naturally occurring radioactive materials (NORM) that are disposed of at DOE burial or commercial disposal sites are not treated as separate entities in this chapter. Mill tailings are considered in Chapters 5 and 6. Another waste not included in this chapter is "mixed" waste that contains chemically hazardous constituents as well as radioactivity (see Chapter 8). The DOE generates LLW through defense activities, uranium enrichment operations, the naval nuclear propulsion program, and various R&D activities.

Commercial nuclear fuel cycle facilities currently account for slightly over 70% of the waste volume that is shipped to commercial disposal sites; the remainder comes from industrial/institutional (I/I) activities, that is, radiochemical manufacturers, research laboratories, hospitals, medical schools, universities, other radioactive materials licensees, and some non-DOE government agencies. More than 20,000 licenses have been issued by the NRC and the "Agreement States" for handling and use of radionuclides.

Some LLW is also generated by environmental restoration programs, and these are discussed in Chapter 6. Other LLW will be generated in future years by nonroutine D&D operations. Waste from commercial D&D operations in the past is included with industrial waste in this chapter. However, projections of D&D wastes are not included here; D&D waste projections for commercial fuel cycle facilities are discussed in Chapter 7.

The categorization of LLW according to DOE activities, commercial fuel cycle operations, and I/I applications permits a comparison of the types, activities, and volumes of waste arising from each of these major sources (Figs. 4.1 and 4.2). Summary data on DOE LLW are given in Table 4.1. In Table 4.2, similar data are shown for commercial LLW disposal based on a fuel cycle without spent fuel reprocessing. A plot showing a comparison of historical and projected LLW volumes for DOE and commercial (which includes some non-DOE government agencies) sources is shown in Fig. 4.3.

4.2 DOE LLW

4.2.1 Inventories at DOE LLW Disposal Sites

Prior to October 1979, some LLW generated by DOE contractors was shipped to commercial disposal sites. Currently, all LLW generated by DOE activities is buried at DOE sites (Figs. 4.4 and 4.5). A summary of historical additions, accumulated volumes, and accumulated undecayed radioactivity for solid LLW buried at all DOE sites through 1989 is presented in Tables 4.1, 4.3, and 4.4. The data in these tables are derived from the Solid Waste Information Management System (SWIMS) and subsequent site questionnaires obtained through the Hazardous Waste Remedial Action Program (HAZWRAP) at ORNL.[1]

There are small quantities of DOE LLW that have been disposed of by sea dumping or by hydrofracture;[2] these wastes are not included in the SWIMS data base. Sea dumping of LLW was halted by the United States in 1970, and hydrofracture was terminated in 1983; Table 4.5 shows the estimated quantity and radioactivity of LLW disposed of by methods other than shallow-land burial (viz., sea dumping and hydrofracture).

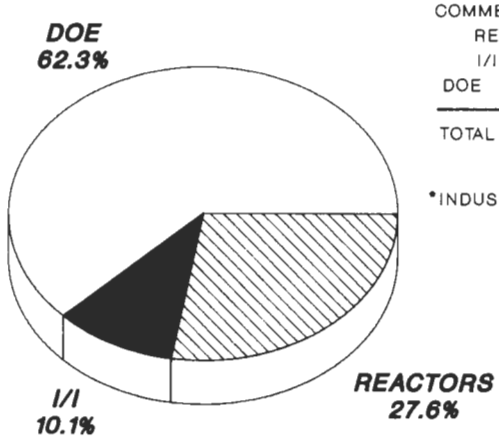
4.2.2 Characterization of LLW at DOE Sites

Representative radionuclide characteristics for buried DOE LLW (calculated from information in ref. 1) are given for each site in Table 4.4. Representative radionuclide compositions for the waste types have been developed[3] and are given in Table A.5 of Appendix A.

Most of the DOE wastes that were disposed of by sea dumping (Table 4.5) were incorporated into cement matrix material and packaged in steel drums (55- or 80-gal capacity).

Hydrofracture was developed at ORNL for the permanent disposal of locally generated, low-level (approximately 0.25 Ci/L) liquid waste concentrates.[4]

ORNL DWG 90-8280

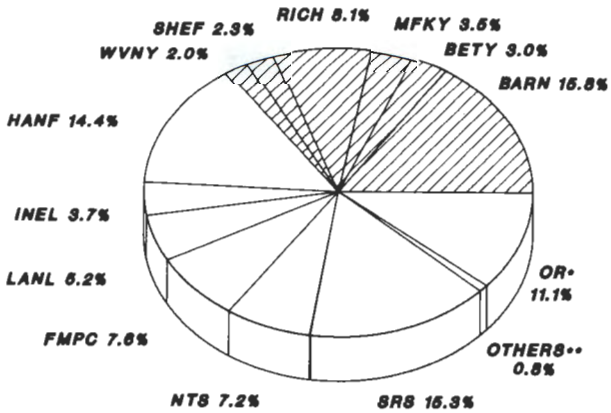


SOURCE	CUBIC METERS
COMMERCIAL	
REACTORS	3.37E+04
I/I*	1.24E+04
DOE	7.62E+04
TOTAL	12.23E+04

*INDUSTRIAL/INSTITUTIONAL

Fig. 4.1. Volume of LLW disposed in 1989.

ORNL DWG 90-8281



SITE	CUBIC METERS
BARN	6.16E+05
BETY	1.17E+05
MFKY	1.35E+05
RICH	3.16E+05
SHEF	8.83E+04
WVNY	7.71E+04
HANF	5.64E+05
INEL	1.43E+05
LANL	2.05E+05
FMPC	2.99E+05
NTS	2.80E+05
OR*	4.34E+05
SRS	5.99E+05
OTHERS**	3.31E+04
TOTAL	3.91E+06

*Includes contributions from ORNL, Y-12, and ORGDP.

**Includes contributions from PANT, SNLA, LLNL, BNL, PAD, and PORTS.

▨ Commercial

□ DOE

Fig. 4.2. Total volume of LLW disposed through 1989.

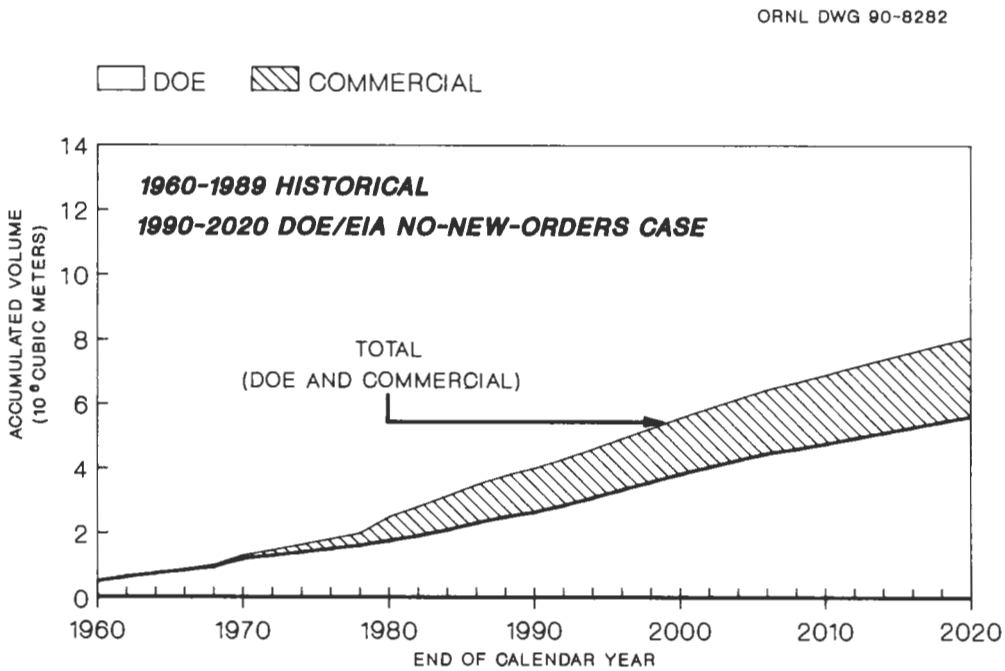
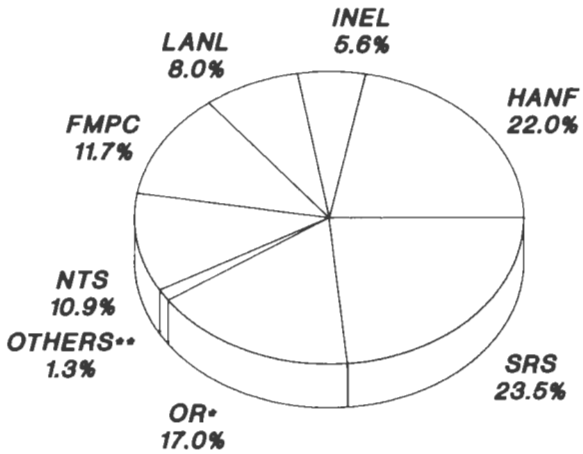


Fig. 4.3. Historical and projected accumulated volume of LLW.

ORNL DWG 90-8283



SITE	CUBIC METERS
HANF	5.64E+05
INEL	1.43E+05
LANL	2.05E+05
FMPC	2.99E+05
NTS	2.80E+05
OR*	4.34E+05
SRS	5.99E+05
OTHERS**	3.31E+04
TOTAL	2.56E+06

*Includes contributions from ORNL, Y-12, and ORGDP.

**Includes contributions from PANT, SNLA, LLNL, BNL, PAD, and PORTS.

Fig. 4.4. Total volume of disposed DOE LLW through 1989.

ORNL DWG 90-8284

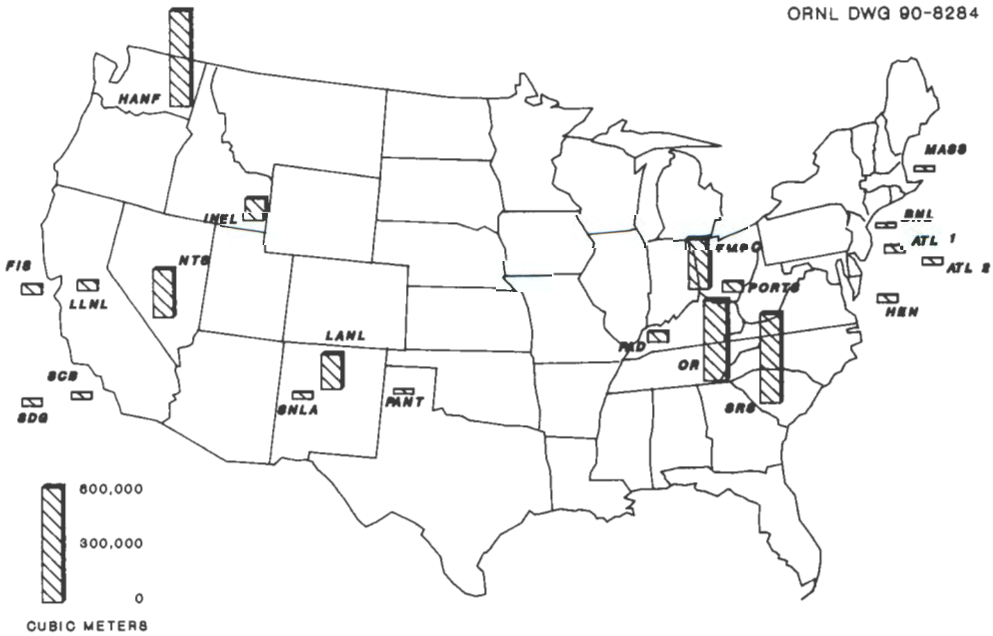


Fig. 4.5. Locations and total volumes of disposed DOE LLW through 1989.

Waste was mixed with a blend of cement and other additives, and the resulting grout was injected into shale at a depth of 200 to 300 m. The injected grout hardened into thin, horizontal sheets several hundred meters wide.

4.2.3 DOE LLW Disposal Sites

Data on the current status of the principal DOE LLW disposal sites (Table 4.6) are based on average land usage factors that were calculated from historical data.[2] These factors were then used to estimate the area needed to bury the amount of waste received during 1989.[1] For each site, the calculated area needed in 1989 was added to the utilized area reported at the end of 1988[5] to obtain the value shown for estimated burial area utilized through 1989.

As previously discussed, the LLW ocean disposal sites have not been used since 1970. All of the liquid LLW that had been held in long-term storage at ORNL was disposed of during 1982 and 1983 using the new hydrofracture facility.

Revisions and corrections that have been made in historical inventory data, waste characteristics data, and disposal site status during 1988 are summarized in Table 4.7.

4.2.4 DOE LLW Projections

An assumption used in this report is that the level of DOE waste burial activities will remain constant through 2020. Beginning in 1990, the volume added each year is assumed to remain constant through 2020 at the last value reported by a site (i.e., the 1989 volume or, if provided, the 1990 projected volume). This volume for a site and the average specific activity for the site based on historical additions (see Table 4.4) are used to determine the annual radioactivity addition for each site. This total activity is split into waste types using the fractions presented in Table 4.4. The radioactivity (by waste type) is decayed from the year of addition using the representative compositions given in Table A.5 of Appendix A.

Projections for burial of DOE LLW are presented in Tables 4.1, 4.8, and 4.9. Table 4.9 summarizes projections of saltstone, a LLW by-product from the solidification of HLW at SRS. This saltstone (see Fig. A.10 and Table A.7 of Appendix A) is to be stored in trenches at SRS. The grout-immobilized LLW derived from processing double-shell waste at Hanford (see Fig. 2.7 in Chapter 2) is excluded from the projections in Table 4.1, because the schedule and formulation for solidification are not yet firmly defined.

4.3 COMMERCIAL LLW

4.3.1 Inventories at Commercial LLW Disposal Sites

There are six commercial shallow-land disposal sites for LLW (Figs. 4.2, 4.6, and 4.7), but only three are currently in operation. Commercial operations at the Maxey Flats, West Valley, and Sheffield sites have been halted. Until 1986, a second NRC-licensed burial ground at West Valley continued to receive wastes generated on-site from cleanup and water treatment operations. However, disposal operations at the WVDP have been suspended since 1986 pending the preparation of an Environmental Impact Statement (EIS) report for the West Valley site closure. The historical data for annual additions and inventories of volume and radioactivity (undecayed) at each commercial disposal site through the end of 1989 are listed in Tables 4.10 and 4.11, respectively (compiled from refs. 2, 5–10). The volumes are depicted in Figs. 4.2, 4.3, 4.6, and 4.7. Sources of the historical reported data through 1984 are given in ref. 2. Quantities of LLW shipped to disposal during 1989 are listed in Table 4.12 on a state-by-state basis.[7] These state-by-state values reflect the fact that the new Manifest Information Management System (MIMS) is able to assign, to the original shippers, the LLW collected and treated by waste brokers. Table 4.2 is a summary of historical and projected volumes and radioactivity (decayed) for commercial LLW. Not included in Table 4.2 are the drums of cemented LLW to be generated by the WVDP as a result of the vitrification of HLW. This LLW from the WVDP is described in Table A.10 of Appendix A.

About 5 vol % of the LLW shipped to commercial sites is from government operations other than DOE[6] and in this chapter is included in I/I waste. Since the end of 1980, individual states have been encouraged to form compacts for the purpose of developing new regional LLW disposal sites.[11] The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) stipulates areas of responsibility in LLW disposal and defines penalties for future noncompliance.[12]

4.3.2 Characterization of LLW at Commercial Disposal Sites

All of the LLW accepted for commercial disposal is classified A, B, or C in compliance with NRC specifications.[13] The LLW that exceeds these specifications is currently in storage (see Sect. 4.3.3). A calculated representative radionuclide composition for commercial LLW is given in Table A.6 of Appendix A. This composition is periodically updated to reflect changes in waste management practices and in the regulations governing LLW disposal.

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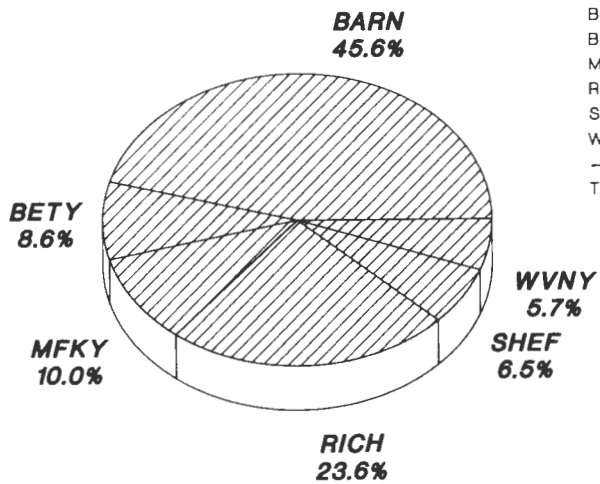

SITE	CUBIC METERS
BARN	6.16E+05
BETY	1.17E+05
MFKY	1.35E+05
RICH	3.18E+05
SHEF	8.83E+04
WVNY	7.71E+04
TOTAL	1.35E+06

Fig. 4.6. Total volume of disposed commercial LLW through 1989.

ORNL DWG 90-8286

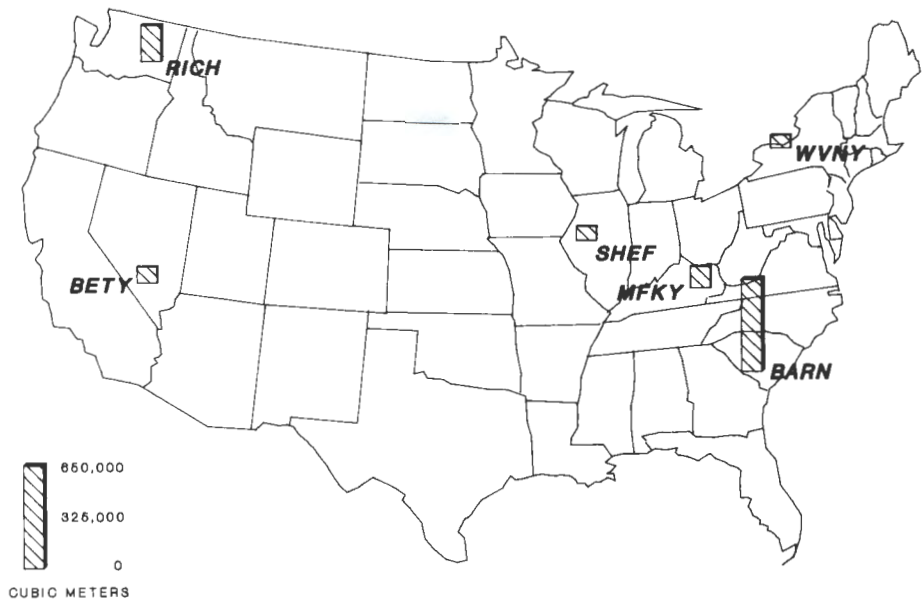

Fig. 4.7. Locations and total volumes of disposed commercial LLW through 1989.

The LLW from nuclear power plant operations accounts for approximately 60% of the waste volume shipped to commercial disposal sites (other fuel cycle operations account for about 13%). Nuclear power plants in the United States are of two basic types: boiling-water reactors (BWRs) and pressurized-water reactors (PWRs) (Figs. A.6 and A.7 of Appendix A). The BWRs are further classified as deep-bed or filter/demineralizer types, depending on the condensate cleanup system employed. The reference BWR used in this report is an average composite, based on the historical net electricity generation of both types. Although nonroutine, irradiated-component LLW is disposed of only sporadically, it accounts for a large portion of the total radioactivity (but only a minuscule portion of the volume) of the LLW shipped to disposal from nuclear power plants (see Table A.9 of Appendix A). Characteristics of LLW from the other fuel cycle facilities that ship to commercial disposal sites (UF_6 conversion and fuel fabrication) are presented in Figs. A.2, A.3, and A.5 of Appendix A.

Characteristics of the I/I wastes are presented in Table A.11 of Appendix A. Industrial LLW sources include, among others, radiochemical and pharmaceutical companies and manufacturers of smoke detectors and luminous dials. In March 1981, the NRC removed some of the restrictions on the disposal of radioactive biomedical waste.[14] This was done to decrease the volumes of very low-level radioactive waste shipped to NRC-licensed commercial disposal facilities from hospitals, laboratories, medical schools, and other institutions. Representative characteristics of this institutional waste indicate three distinct waste streams, which can be categorized as bioresearch, nonbioresearch, and medical. This categorization was suggested by the University of Maryland in a survey published in 1979 (see ref. 2 for a succinct summary). Bioresearch waste results mainly from chemical tracers used in animal studies; nonbioresearch waste is derived from physical and earth science studies; and medical waste comes from medical diagnostic and therapeutic practices.

4.3.3 Greater-Than-Class C Low-Level Waste (GTCC LLW)

In 1980, federal law made each state responsible for providing the disposal capacity for LLW generated within its borders, except for certain waste generated by the federal government.[11] In 1983, 10 CFR Part 61 (ref. 13) codified disposal requirements for three classes of LLW, as mentioned above, generally suitable for near-surface disposal, namely, A, B, and C (with Class C waste requiring the most rigorous disposal specifications). Waste with concentrations above Class C limits for certain short- and long-lived radionuclides (i.e., GTCC LLW) was found not generally suitable for near-surface disposal, except on a case-by-case evaluation of the waste and the proposed disposal method by NRC or state licensing agency. The LLRWPAA[12] made the states responsible for the disposal of Classes A, B, and C LLW and made the federal government (viz., DOE) responsible for disposal of GTCC LLW. The law also required that GTCC LLW generated by licensees of NRC be disposed of in a facility licensed by NRC. The projected amounts of GTCC LLW are uncertain, both because of regulatory uncertainties affecting the definition of HLW and because of the lack of information on the sources, volumes, and characteristics of GTCC LLW.[15]

In May of 1989, NRC promulgated a rule that amended 10 CFR 61 and required disposal of GTCC LLW in a deep geologic repository unless disposal elsewhere has been approved by NRC.[16] The rule as amended states: "Waste that is not generally acceptable for near-surface disposal is waste for which form and disposal methods must be different and, in general, more stringent than those specified for Class C waste. In the absence of specific requirements in this part, such waste must be disposed of in a geologic repository as defined in Part 60 of this chapter unless proposals for disposal of such waste in a disposal site licensed pursuant to this part are approved by the Commission." A disposal facility for GTCC LLW will probably not be available for several decades due to the complexities of siting and NRC licensing.

Existing volume projections of GTCC LLW vary, ranging from 2000 m^3 in the 1987 report to congress,[15] to 17,000 m^3 in the update of Part 61 Impacts Analysis Methodology.[17] In order to develop a set of volume projections to serve as a basis for further planning, DOE has initiated a structured internal and external review of the technical and regulatory issues that have caused the wide variation in previous projections. This effort will result in a final report near the end of calendar year 1990 that will provide high-, low-, and planning-base-case projections.

4.3.4 Commercial LLW Disposal Sites

Three commercial LLW disposal sites in the eastern United States (Maxey Flats, Sheffield, and West Valley) have been closed to further use. Only a small amount of on-site generated LLW from site cleanup is occasionally buried at Maxey Flats. The closure of these three commercial LLW disposal sites resulted in increasing volumes of LLW being shipped to the three remaining operating sites in South Carolina, Nevada, and Washington. The increase prompted South Carolina to impose a cap on the volume of LLW that could be accepted at Barnwell. Eventually, a general concern developed that the responsibility for LLW disposal should not rest with only three states and that a coordinated national plan was needed. As described above, the LLRWPA[11] was passed in 1980, making each state responsible for its own LLW and encouraging formation of regional interstate compacts to deal with the disposal problem. The Act provided that any compact approved

by Congress could restrict access to its LLW disposal facility to member states after Jan. 1, 1986. However, by 1984, it became evident that no new regional disposal facilities would be operating by the end of 1985. This gave rise to new legislation, the LLRWPAA,[12] which continued to encourage interstate compact formation while requiring that nonsited (i.e., without an operating disposal site) states and compacts meet specific milestones, leading to the operation of new regional facilities by Jan. 1, 1993. Additionally, the LLRWPAA[12] established rates and limits of acceptance at the three commercial disposal sites now in operation, as well as space allocations for utility wastes. The utilities are required to meet certain waste volume reductions during a 7-year transition period which is provided for the opening of new LLW disposal sites under state compact arrangements. The full impact of the law is being studied and evaluated by the nuclear industry as well as by federal and state regulators.

Barnwell now receives about 68% of the total volume of commercial LLW shipped. The Beatty, Nevada, site is receiving about 7%, while the site at Richland, Washington, now receives about 25% (see Table 4.10). The nationwide distribution of this waste among the various LLW categories is shown in Fig. 4.1. Chem-Nuclear Systems, Inc., operates the Barnwell disposal site, and U.S. Ecology, Inc., operates the disposal sites at both Beatty and Richland. The land usage at existing commercial disposal sites is summarized in Table 4.6.

4.3.5 Commercial LLW Projections

All fuel-cycle LLW projections in this report are based on the EIA No-New-Orders Case (Chapter 1 and Table A.8 of Appendix A), the fuel requirements needed to support this scenario, and the various processing steps required to provide the fuel. The source terms used in projecting the volume and radioactivity of commercial LLW are derived from reported historical data.[2,3,5,6,10,18-21] The UF_6 conversion and fuel fabrication LLW source terms (Figs. A.2, A.3, and A.5 of Appendix A) are taken from ref. 3. The reported historical waste data for BWR and PWR plants[6,10,19-21] and their net electrical outputs[18,19,21] provide the data for the reactor source terms in Figs. A.6 and A.7 of Appendix A. A summary of the nonroutine irradiated core component LLW[19-21] is given in Table A.9 of Appendix A. The source term composition used for I/I waste projections (Table 4.14) is presented in Table A.11 of Appendix A. The historical values for the volume and radioactivity of I/I wastes were obtained as the difference between the total volume (Table 4.10) and radioactivity (Table 4.11) reported shipped for disposal each year and the corresponding total fuel cycle (UF_6 conversion and fuel fabrication plus LWR) values from Tables 4.15–4.19. The composition of the radioactivity in pre-1980 I/I waste is given in ref. 2.

The projections for LLW resulting from nuclear reactor operations, normalized to the net electrical generation, are presented in Tables 4.15–4.17. The calculated historical and projected data for UF_6 conversion are given in Table 4.18; similar data for fuel fabrication are presented in Table 4.19. The UF_6 conversion and fuel fabrication facilities account for about 10 vol % of the total fuel-cycle LLW, while reactor operations account for the remaining approximately 90 vol %. These projections may be modified by the new legal changes. Under the LLRWPAA,[12] permissible waste volumes from reactors are not related directly to electrical generating capacity but are based on the reactor type (BWR or PWR) and its present and anticipated operating status.

The basis for the LLW projections from I/I sources (Table 4.14) was the assumption that the average annual addition of these wastes will remain essentially constant from 1989 through 2020, because most measures to maximize volume reduction and minimize the radioactivity of these wastes have already been put into practice.[22]

Table 4.2 summarizes the LLW projected to result from I/I and commercial fuel-cycle sources through the year 2020. These waste projections may be altered as the I/I waste source terms are updated and the provisions in the LLRWPAA[12] are implemented.

The LLW that will be generated by the future D&D of fuel-cycle facilities is not included in the commercial LLW projections (see Chapter 7). Former commercial facilities that will be affected by environmental restoration activities are discussed in Chapter 6 and are also excluded from these projected values.

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Table 4.1. Historical and projected volume, radioactivity, and thermal power of DOE LLW[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	58.2	1,744	436	10,912	1,752	14,464
1981	62.3	1,807	1,119	11,029	3,958	15,400
1982	89.5	1,896	1,941	11,951	6,305	18,661
1983	90.2	1,986	1,800	12,454	3,805	17,971
1984	89.9	2,076	1,432	12,825	3,023	17,973
1985	120.8	2,197	981	12,804	1,772	16,991
1986	94.8	2,292	792	12,705	1,255	16,086
1987	98.4	2,390	2,595	14,513	4,778	19,249
1988	90.3	2,481	399	13,554	1,474	16,349
1989	76.2	2,557	1,119	13,771	5,068	19,389
1990	67.7	2,624	1,483	13,869	2,636	17,275
1991	96.0	2,720	1,495	14,320	2,650	17,179
1992	110.8	2,831	1,508	14,785	2,660	17,248
1993	120.8	2,952	1,512	15,237	2,664	17,363
1994	119.9	3,072	1,507	15,663	2,661	17,492
1995	121.6	3,194	1,502	16,062	2,656	17,621
1996	124.1	3,318	1,498	16,437	2,651	17,746
1997	119.9	3,438	1,507	16,803	2,658	17,877
1998	123.3	3,561	1,497	17,140	2,651	17,997
1999	122.4	3,683	1,495	17,459	2,650	18,117
2000	120.7	3,804	1,493	17,760	2,649	18,232
2001	110.8	3,915	1,492	18,046	2,649	18,345
2002	110.8	4,026	1,491	18,317	2,649	18,456
2003	110.8	4,137	1,490	18,574	2,648	18,565
2004	110.8	4,247	1,490	18,818	2,648	18,672
2005	110.8	4,358	1,490	19,050	2,648	18,776
2006	95.9	4,454	1,489	19,271	2,647	18,879
2007	70.9	4,525	1,483	19,476	2,636	18,967
2008	71.0	4,596	1,483	19,670	2,636	19,056
2009	70.9	4,667	1,483	19,855	2,636	19,142
2010	85.9	4,753	1,483	20,031	2,636	19,227
2011	85.9	4,839	1,483	20,198	2,636	19,312
2012	85.9	4,925	1,485	20,359	2,639	19,398
2013	85.9	5,011	1,485	20,511	2,639	19,482
2014	85.9	5,097	1,485	20,656	2,639	19,565
2015	85.9	5,183	1,485	20,794	2,639	19,647
2016	85.9	5,269	1,485	20,925	2,639	19,726
2017	85.9	5,355	1,485	21,049	2,639	19,805
2018	85.9	5,440	1,485	21,167	2,639	19,882
2019	85.9	5,526	1,485	21,280	2,639	19,959
2020	85.9	5,612	1,485	21,387	2,639	20,034

[a]Summation of values in Tables 4.8 and 4.9 (LLW saltstone at SRS).
[b]The radioactivity added each year for each waste type is decayed as described in the footnotes of Tables 4.8 and 4.9.

Table 4.2. Historical and projected volume, radioactivity, and thermal power of commercial LLW shipped for disposal[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	92.4	768	333	4,547	1,322	8,003
1981	83.7	852	280	4,483	1,092	7,961
1982	76.5	929	414	4,568	2,539	9,442
1983	78.0	1,007	506	4,732	3,604	11,860
1984	76.4	1,083	601	4,954	4,405	14,769
1985	76.7	1,160	749	5,282	5,680	18,580
1986	53.2	1,213	234	5,059	1,619	17,991
1987	52.2	1,265	270	4,924	2,035	18,072
1988	40.5	1,306	260	4,793	1,948	18,095
1989	46.1	1,352	867	5,284	7,568	23,776
1990	37.2	1,389	499	5,300	3,745	24,804
1991	37.9	1,427	504	5,325	3,787	25,854
1992	37.9	1,465	506	5,344	3,801	26,820
1993	38.3	1,503	510	5,362	3,832	27,726
1994	38.3	1,541	509	5,373	3,822	28,537
1995	38.4	1,580	512	5,384	3,850	29,305
1996	38.6	1,618	514	5,394	3,863	30,017
1997	38.7	1,657	516	5,404	3,876	30,682
1998	38.9	1,696	520	5,416	3,907	31,324
1999	38.9	1,735	519	5,426	3,901	31,905
2000	39.0	1,774	521	5,437	3,918	32,459
2001	39.2	1,813	524	5,450	3,940	32,994
2002	39.3	1,852	526	5,464	3,955	33,503
2003	39.4	1,892	528	5,479	3,970	33,991
2004	39.6	1,931	530	5,496	3,986	34,460
2005	39.6	1,971	532	5,514	4,003	34,913
2006	39.8	2,011	534	5,534	4,019	35,353
2007	39.8	2,051	535	5,554	4,026	35,772
2008	39.8	2,090	536	5,575	4,037	36,176
2009	39.8	2,130	534	5,594	4,019	36,538
2010	39.4	2,170	522	5,601	3,923	36,785
2011	37.5	2,207	486	5,575	3,631	36,738
2012	36.4	2,243	461	5,533	3,426	36,528
2013	34.0	2,278	426	5,468	3,146	36,101
2014	30.5	2,308	354	5,347	2,565	35,188
2015	30.0	2,338	348	5,247	2,518	34,390
2016	28.4	2,366	321	5,139	2,307	33,514
2017	27.8	2,394	314	5,044	2,253	32,731
2018	27.3	2,422	304	4,957	2,172	31,995
2019	27.2	2,449	303	4,883	2,158	31,364
2020	26.5	2,475	295	4,813	2,097	30,776

[a]The values in this table are a summation of the corresponding values in Tables 4.14–4.19.

[b]The radioactivity added each year for each waste type is decayed as described in the footnotes of Tables 4.14–4.19.

Table 4.3. Historical annual additions and total volume of LLW buried at DOE sites[a]

Year	Volume of waste buried annually, 10^3 m^3										
	LANL	INEL	NTS	ORNL	HANF	SRS	FMPC	Y-12	All other[b]	Total annual addition	Total volume accumulated
1975[c]	131.6	85.2	8.3	181.5	357.9	269.1	264.7	58.4	83.9	1,440.8	1,441
1976	8.8	6.2	2.9	3.8	5.2	8.1	14.4	2.7	0.9	53.1	1,494
1977	3.6	6.5	0.9	2.4	11.2	14.7	2.8	1.5	1.1	44.7	1,539
1978	7.5	6.7	13.0	2.0	10.3	15.5	1.9	1.4	3.2	61.5	1,600
1979	4.9	5.3	34.0	2.1	17.8	18.2	1.6	1.1	1.1	86.0	1,686
1980	4.8	5.1	12.4	2.0	11.0	19.6	1.3	1.4	0.7	58.2	1,744
1981	5.5	3.1	14.6	1.4	13.3	20.1	1.5	1.2	1.6	62.3	1,807
1982	4.5	3.0	39.2	1.3	12.0	22.4	2.8	2.2	2.0	89.5	1,896
1983	3.2	5.4	26.6	1.8	18.2	26.7	3.4	3.4	1.7	90.2	1,986
1984	5.4	3.8	12.1	2.2	19.0	26.1	3.5	7.2	10.6	89.9	2,076
1985	6.7	3.1	39.4	2.2	17.4	30.5	0.7	18.7	2.1	120.8	2,197
1986	4.5	3.4	17.9	1.8	21.2	30.1	0	15.0	1.0	94.8	2,292
1987	3.7	3.0	19.5	0.5	20.4	34.2	0	16.2	1.0	98.4	2,390
1988	4.3	2.0	18.5	0.6	16.8	36.7	0	10.5	1.0	90.3	2,481
1989	6.4	1.3	20.6	1.3	11.9	26.8	0	5.7	2.1	76.2	2,557
Total	205.4	143.1	279.9	206.9	563.6[d]	598.8	298.5	146.5	114.1	2,557	

[a]No TRU waste included; data from ref. 1 and site questionnaires. Slight differences in values shown and those actually reported result from rounding off and truncation of numbers.

[b]Includes ORGDP, PAD, PORTS, PANT, SNLA, LLNL, and BNL. See Table 4.4 for breakdown of 1989 accumulation.

[c]Values for 1975 are cumulative volumes to this date.

[d]Does not include 5,190 m^3 of grouted liquid LLW disposed of at Hanford.

Table 4.4. Volumes and undecayed radionuclide characteristics of LLW buried at DOE sites[a]

Site	Accumulated volume (10^3 m^3)	Total gross activity (Ci)[b]	Average specific activity (Ci/m^3)[c]	Waste type (fraction of total Ci)[d]					
				Uranium/ thorium[e]	Fission products	Induced activity	Tritium	Alpha (<100 nCi/g)	Other activity
Principal									
LANL	205.4	1.10E+06	5.36E+00	2.27E-04	1.62E-02	2.23E-02	9.58E-01	3.69E-03	--
INEL	143.1	1.05E+07	7.34E+01	2.71E-06	2.81E-01	7.18E-01	--	1.18E-04	--
NTS	279.9	9.09E+06	3.25E+01	1.19E-03	1.02E-02	7.29E-04	9.53E-01	5.79E-03	2.91E-02
ORNL	206.9	1.25E+06	6.04E+00	1.30E-03	2.01E-01	4.51E-01	6.31E-03	4.98E-04	3.40E-01
HANF[f]	563.6	8.09E+06	1.44E+01	6.18E-04	7.87E-01	1.62E-01	5.08E-02	--	--
SRS	598.8	1.05E+07	1.75E+01	9.48E-06	6.87E-02	4.64E-01	4.44E-01	4.99E-04	2.28E-02
Subtotal	1,997.7	4.05E+07							
All others									
FMPC	298.5	1.84E+03	6.16E-03	1.00E+00	--	--	--	--	--
PAD	7.6	2.04E+04	2.68E+00	1.00E+00	1.25E-04	--	2.94E-05	--	--
ORGDP	81.0	5.64E+01	6.96E-04	1.00E+00	--	--	--	--	--
Y-12	146.5	1.01E+04	6.89E-02	1.00E+00	--	--	--	--	--
PANT	0.1	7.61E+00	7.61E-02	9.97E-01	--	2.38E-03	--	1.45E-08	--
SNLA	3.3	9.26E+03	2.81E+00	1.98E-03	6.71E-02	6.03E-01	3.27E-01	3.16E-04	3.45E-04
LLNL	9.1	1.34E+01	1.47E-03	9.99E-01	3.25E-04	1.07E-03	--	--	--
BNL	0.8	5.49E+00	6.86E-03	--	--	3.61E-01	5.08E-01	--	1.31E-01
PORTS	12.1	2.58E+01	2.13E-03	1.00E+00	--	--	--	--	--
Subtotal	559.0	4.17E+04							
Total	2,556.7	4.06E+07							

[a]As of Dec. 31, 1989. No TRU waste is included. From data in ref. 1 and site questionnaires. All volumes are based on container volumes.

[b]Decay has not been allowed for. Present activities are less than the sum of what was buried (see Table 4.8).

[c]Average specific activity is the ratio of the total gross activity (undecayed) to the accumulated volume (as of Dec. 31, 1989) for each site.

[d]Failure of the sum of fractions for a site to total unity results from rounding off and truncation of numbers.

[e]Total metal = 2.84×10^7 kg.

[f]Does not include 5,190 m^3 of grouted liquid LLW disposed of at Hanford.

Table 4.5. DOE LLW disposed by methods other than shallow-land burial[a]

Site	Location	Site use (year)	Waste containers buried[b]	Undecayed radioactive content (Ci)
		Atlantic Ocean		
Atlantic	38°30′N 72°06′W	1951–1956; 1959–1962	14,300	74,400[c]
Atlantic	37°50′N 70°35′W	1957–1959	14,500	2,100
Massachusetts Bay	42°25′N 70°35′W	1952–1959	4,008	2,400
Cape Henry	36°56′N 74°23′W	1949–1967	843	87
Central Atlantic	36°20′N/ 43°49′N 45°00′W	1959–1960	432	480
Subtotal			34,083	79,507
		Pacific Ocean		
Farallon Islands (Subsite A)	37°38′N 123°08′W	1951–1953	3,500	1,100
Farallon Islands (Subsite B)	37°37′N 123°17′W	1946–1950; 1954–1956	44,000	13,400
Santa Cruz Basin	33°40′N 119°40′W	1946–1962	3,114	108
Cape Scot	50°56′N 136°03′W 52°25′N 140°12′W	1958–1969	360	124
San Diego	32°00′N 121°30′W	1959–1962	4,415	34
Subtotal (oceans)			55,389	14,766
Total			89,472	94,273
		Hydrofracture facility		
ORNL	Bedded Conasauga shale underlying the ORNL site	1959–1965	Small experimental amounts	
		1966–1980[d]	8.0×10^3 m^3 of grout	600,000
		1982[e]	3.8×10^3 m^3 of grout	200,000
		1983[e]	5.5×10^3 m^3 of grout	500,000
Total			17.3×10^3 m^3	1,300,000

[a]Not included in the SWIMS data base for DOE LLW. Radioactivity is given at time of burial. Data taken from Table 4.5 of ref. 3.
[b]Estimated number of containers.
[c]Includes approximately 33,000 Ci of induced activity associated with the U.S.S. Seawolf reactor vessel.
[d]Retired after 18 injections.
[e]New facility started up with four injections in 1982 and completed campaign with seven injections in 1983.

Table 4.6. Status of land usage at LLW burial and disposal sites

Site	Site size[a] (ha)	Estimated total usable area[a] (ha)	Calculated land usage factor[a] (m^3/ha)	Estimated area utilized through 1989 (ha)[b]
DOE (burial sites)				
LANL	47.2	24.7	29,490	16.8
INEL	35.6	31.6	20,000	28.6[c]
NTS	42.5	d	d	d
ORNL	27.5	5.8	6,580	5.0
HANF[e]	382.0	236.0	4,921	146.0
SRS	78.8	72.7	11,150	70.2
Total	614	>370.8		>266.6
Commercial (disposal sites)				
West Valley, NY (Closed Mar. 11, 1975)	8.9	7.2	20,283[f]	3.8[f]
Maxey Flats, KY (Closed Dec. 27, 1977)	102	<51	13,590	10.4
Sheffield, IL (Closed Apr. 8, 1978)	8.9	8.1	10,905	8.1
Barnwell, SC[g]	110	48.0	20,312[h]	30.3[h]
Beatty, NV[g]	32	18.6	7,419[h]	15.7[h]
Richland, WA[g]	40	35.4	42,203[h]	7.6[h]
Total	302	168		75.9
Grand total	916	>538.8		

[a]The historical bases for site size, estimated usable area, and calculated land usage factor are given in Table 4.5 of ref. 3. Note: 1 acre = 0.405 ha.

[b]Calculated by dividing volume added in 1989 by the average land usage factor to obtain area used in 1989. This value was added to the 1988 value reported in Table 4.11 in ref. 5. See also Tables 4.3 and 4.10 in this report, and Fig. 1 in ref. 9.

[c]In addition, prior to 1970, about 2 ha was used for TRU waste which was considered to be LLW at the time of burial.

[d]This pertains to the radioactive waste management site in Area 5 of the NTS. The availability of land that could be used for shallow-land burial is not clearly defined because of the classified nature of the site and the abundance of land. A land usage factor is not applicable at NTS.

[e]Utilized land value is for the 200-Area only; in addition, the closed 100- and 300-Area burial grounds include a total of about 16.8 ha. The land usage factor is an all-time value obtained by dividing the total volume buried (Table 4.3) by the reported utilized area. However, the land usage factors have been increasing in recent years and, in 1988 it was 5,453 m^3/ha and in 1989 it was 8,498 m^3/ha.

[f]WVDP LLW was buried on-site in the noncommercial NRC disposal area from 1982 until late 1986. No waste was buried at West Valley in 1987, 1988 or 1989 (see Table 4.10).

[g]Anticipated closure date for this site is December 31, 1992.

[h]Calculated from total capacity data given in ref. 10 and total disposed volume data in Table 4.10 in this report.

Table 4.7. Revisions and corrections made in 1989 to historical LLW inventory data

Burial site	DOE/RW-0006, Rev. 5 (1989)		DOE/RW-0006, Rev. 6 (1990)			Explanation
	Table No.	Reported value	Table No.	Reported value	Net change	
HANF						
Volume of waste buried annually, 10^3 m^3	4.3		4.3			Redefinition and revision of historical buried LLW at Hanford. Some suspect TRU or mixed waste was checked and redefined as LLW or vice versa. These differences are reflected in the total annual addition and accumulated volume for each year
1975		349.9		357.9	+8.0	
1976		4.7		5.2	+0.5	
1977		10.8		11.2	+0.4	
1978		9.9		10.3	+0.4	
1979		15.8		17.8	+2.0	
1980		10.6		11.0	+0.4	
1881		12.9		13.3	+0.4	
1982		11.7		12.0	+0.3	
1983		18.0		18.2	+0.2	
1984		18.7		19.0	+0.3	
1985		17.0		17.4	+0.4	
1986		21.2		21.2	0.0	
1987		21.5		20.4	-1.1	
1988		16.7		16.8	+0.1	
Total		539.5		563.6	+24.1	
Accumulated volume, 10^3 m^3	4.4	539.5	4.4	563.6	+24.1	Same as above
Summation of activity at time of burial, Ci	4.4		4.4			In the past, tritium was not reported separately because of national security. The fission product and induced activity value reductions are probably due to a change in the source of information that started this year
Fission product		6.44×10^6		6.36×10^6	-8.00×10^4	
Induced activity		1.47×10^6		1.31×10^6	-1.60×10^5	
Tritium		0		4.11×10^5	$+4.11 \times 10^5$	
Calculated land usage factor, m^3/ha	4.8	3,747	4.6	4,921	+1,194	All-time average based on the new data. For 1989 only, value is 8,498 m^3/ha
LANL						
Site size, ha	4.8	36.4	4.6	47.2	+10.8	Old value includes all (since 1944) closed burial grounds. The only currently operating burial ground is G-site, which is being expanded by 10.8 ha in 1990 and will be ready to receive waste in 1991

Table 4.8. Historical and projected volume, radioactivity, and thermal power characteristics of DOE LLW, except SRS saltstone

End of calendar year	Volume[a,b] (10^3 m^3)		Radioactivity[a,b] (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
1980	58.2	1,744	436	10,912	1,752	14,464
1981	62.3	1,807	1,119	11,029	3,958	15,400
1982	89.5	1,896	1,941	11,951	6,305	18,661
1983	90.2	1,986	1,800	12,454	3,805	17,971
1984	89.9	2,076	1,432	12,825	3,023	17,973
1985	120.8	2,197	981	12,804	1,772	16,991
1986	94.8	2,292	792	12,705	1,255	16,086
1987	98.4	2,390	2,595	14,513	4,778	19,249
1988	90.3	2,481	399	13,554	1,474	16,349
1989	76.2	2,557	1,119	13,771	5,068	19,389
1990	67.7	2,624	1,483	13,869	2,636	17,275
1991	67.7	2,692	1,483	14,308	2,636	17,165
1992	67.7	2,760	1,483	14,750	2,636	17,210
1993	67.7	2,828	1,483	15,178	2,636	17,300
1994	67.7	2,895	1,483	15,587	2,636	17,408
1995	67.7	2,963	1,483	15,977	2,636	17,522
1996	67.7	3,031	1,483	16,348	2,636	17,637
1997	67.7	3,099	1,483	16,700	2,636	17,751
1998	67.7	3,166	1,483	17,033	2,636	17,863
1999	67.7	3,234	1,483	17,350	2,636	17,974
2000	67.7	3,302	1,483	17,650	2,636	18,082
2001	67.7	3,369	1,483	17,935	2,636	18,187
2002	67.7	3,437	1,483	18,205	2,636	18,291
2003	67.7	3,505	1,483	18,461	2,636	18,393
2004	67.7	3,573	1,483	18,704	2,636	18,493
2005	67.7	3,640	1,483	18,935	2,636	18,591
2006	67.7	3,708	1,483	19,155	2,636	18,687
2007	67.7	3,776	1,483	19,363	2,636	18,781
2008	67.7	3,844	1,483	19,560	2,636	18,874
2009	67.7	3,911	1,483	19,748	2,636	18,965
2010	67.7	3,979	1,483	19,926	2,636	19,054
2011	67.7	4,047	1,483	20,095	2,636	19,142
2012	67.7	4,114	1,483	20,256	2,636	19,229
2013	67.7	4,182	1,483	20,409	2,636	19,314
2014	67.7	4,250	1,483	20,554	2,636	19,397
2015	67.7	4,318	1,483	20,692	2,636	19,480
2016	67.7	4,385	1,483	20,823	2,636	19,560
2017	67.7	4,453	1,483	20,947	2,636	19,640
2018	67.7	4,521	1,483	21,066	2,636	19,718
2019	67.7	4,589	1,483	21,179	2,636	19,795
2020	67.7	4,656	1,483	21,286	2,636	19,871

[a]Historical (beginning of operations through 1989) annual values of volume and radioactivity (by waste type) for each site are from ref. 1 and subsequent site questionnaires. See Tables 4.3 and 4.4 for more detail. Radioactivity (by waste type) is decayed from the year of addition using the representative compositions given in Table A.5 of Appendix A.

[b]Beginning in 1990, the volume added each year is assumed to remain constant through 2020 at the last value reported by a site (i.e., the 1989 volume or, if provided, the 1990 projected volume). This volume for a site and the average specific activity for the site based on historical additions (see Table 4.4) are used to determine the annual radioactivity addition for each site. This total activity is split into waste types using the fractions presented in Table 4.4. The radioactivity (by waste type) is decayed from the year of addition using the representative compositions given in Table A.5 of Appendix A.

Table 4.9. Projected volume, radioactivity, and thermal power characteristics of DOE LLW saltstone at SRS[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity[b] (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
1991	28.3	28.3	12.1	12	14	14
1992	43.1	71.4	25.2	35	24	38
1993	53.1	124.5	29.2	59	28	63
1994	52.2	176.7	24.2	76	25	84
1995	53.9	230.6	19.0	85	20	99
1996	56.4	287.0	14.3	89	15	109
1997	52.2	339.2	23.5	103	22	126
1998	55.6	394.8	13.7	107	15	134
1999	54.7	449.5	11.6	109	14	143
2000	53.0	502.5	10.0	110	13	150
2001	43.1	545.6	8.7	111	13	158
2002	43.1	588.7	7.8	112	13	165
2003	43.1	631.8	7.2	113	12	172
2004	43.1	674.9	6.7	114	12	179
2005	43.1	718.0	6.4	115	12	185
2006	28.2	746.2	5.9	116	11	192
2007	3.2	749.4	0.0	113	0	186
2008	3.3	752.7	0.0	110	0	182
2009	3.2	755.9	0.0	107	0	177
2010	18.2	774.1	0.0	105	0	173
2011	18.2	792.3	0.0	103	0	170
2012	18.2	810.5	1.7	103	3	169
2013	18.2	828.7	1.7	102	3	168
2014	18.2	846.9	1.6	102	3	168
2015	18.2	865.1	1.6	102	3	167
2016	18.2	883.3	1.5	102	3	166
2017	18.2	901.5	1.5	102	3	165
2018	18.2	919.7	1.5	101	3	164
2019	18.2	937.9	1.5	101	3	164
2020	18.2	956.1	1.5	101	3	163

[a]Taken from ref. 1 of Chapter 2. Solidification of HLW begins in 1992 at SRS. Feed preparation for this operation begins in 1991 and generates LLW saltstone (see Fig. A.10 and Table A.7 of Appendix A).

[b]Radionuclide composition as a function of time is given in Table A.7 of Appendix A.

Table 4.10. Historical annual additions and total volume of LLW at commercial disposal sites[a]

Year	Volume, m^3							
	Beatty	West Valley[b]	Maxey Flats[c]	Richland	Sheffield[d]	Barnwell	Annual total	Total accumulation
1962	1,861						1,861	1,861
1963	3,512	127	2,206				5,845	7,706
1964	2,836	5,940	3,872				12,648	20,354
1965	1,988	5,192	5,753	668			13,601	33,955
1966	3,533	3,951	5,557	2,402			15,443	49,398
1967	3,206	7,475	7,820	773	2,527		21,801	71,199
1968	3,576	3,490	8,178	1,359	2,713		19,316	90,515
1969	4,526	4,099	10,354	438	2,012		21,429	111,944
1970	5,152	4,906	12,521	423	2,825		25,827	137,771
1971	4,916	7,002	13,173	584	4,430	1,171	31,276	169,047
1972	4,301	9,045	15,578	654	5,956	3,757	39,291	208,338
1973	4,076	7,535	10,074	1,033	8,524	15,839	47,081	255,419
1974	4,103	8,866	8,898	1,411	12,373	18,244	53,895	309,314
1975	4,943	2,243	17,098	1,500	14,116	18,072	57,972	367,286
1976	3,864	427	13,775	2,867	13,480	40,227	74,640	441,926
1977	4,742	351	423	2,718	17,643	45,663	71,540	513,466
1978	8,874	144		7,422	1,735	61,554	79,729	593,195
1979	6,491	138		12,185		63,861	82,675	675,870
1980	12,717	141		24,819		54,723[e]	92,400	768,270
1981	3,351	216		40,732		39,427[e]	83,726	851,996
1982	1,505	632		39,606		34,779	76,522	928,518
1983	1,111	1,284		40,458		35,132	77,985	1,006,503
1984	2,067	966		38,481		34,879	76,393	1,082,896
1985	1,388	809		40,135		34,389	76,721	1,159,617
1986	2,668	2,095		18,833		29,612	53,208	1,212,825
1987	9,414			15,765		27,060	52,239	1,265,064
1988	2,645			11,430		26,391	40,466	1,305,530
1989[f]	3,291			11,562		31,242	46,095	1,351,625
Total	116,657	77,074	135,280	318,258	88,334	616,022		1,351,625

[a]For a summary of historical additions (1962–1984), see Table 4.6 in ref. 3. For operating sites (Beatty, Richland, and Barnwell), the additions for 1985–1987 are from ref. 6 and for 1988–1989 are from ref. 7.

[b]West Valley includes a commercial state-licensed facility which opened Nov. 18, 1963, and closed Mar. 11, 1975, and an NRC-licensed facility (for on-site fuel reprocessing wastes) which opened in 1966 and continued to receive only on-site generated LLW associated with water treatment and site cleanup until late 1986. This license is in abeyance. Disposal operations at the West Valley Demonstration Project (WVDP) have been suspended pending the preparation of an EIS report for the West Valley site closure. The WVDP began in 1982. The LLW volumes reported for 1982 through 1986 are for the WVDP only and are taken from ref. 5. Since the beginning of 1987, LLW generated at the WVDP is stored on-site in engineered facilities pending final disposal (ref. 8).

[c]Closed Dec. 27, 1977. Small perturbations in waste volumes have occurred during site cleanup operations (ref. 9) but are not included here since they are inconsequential.

[d]Closed Apr. 8, 1978. No additional operations have taken place at the site.

[e]These values exclude almost 19,000 m^3 (approximately 14,506 in 1980 and approximately 4,279 in 1981) of very low-level-activity settling pond sludge that was not counted against the annual quota.

[f]This 1989 annual volume addition of 46,095 m^3 is about 23% higher than the 37,400 m^3 predicted for 1989 in Table 4.2 of last year's report (DOE/RW-0006, Rev. 5). These annual volume and radioactivity values (see Table 4.11) are larger than expected. Investigation by DOE's National Low-Level Waste Management Program determined that these larger values are due to normal power plant 10-year maintenance outages.

Table 4.11. Historical annual additions and total undecayed radioactivity of LLW at commercial disposal sites[a]

	Radioactivity, Ci							
Year	Beatty	West Valley[b]	Maxey Flats[c]	Richland	Sheffield[d]	Barnwell	Annual total	Total accumulation
1962								
1963	5,690	100	22,556				28,346	28,346
1964	6,477	10,400	147,218				164,095	192,441
1965	6,377	22,600	63,828	144			92,949	285,390
1966	11,974	35,400	52,737	1,606			101,717	387,107
1967	10,894	123,100	23,273	5,378	3,850		166,495	553,602
1968	6,808	10,600	45,577	64,432	2,381		129,798	683,400
1969	9,761	36,000	31,028	55,964	2,192		134,945	818,345
1970	12,304	91,900	46,969	52,820	5,427		209,420	1,027,765
1971	4,316	436,700	720,146	23,916	7,895	4,151	1,197,124	2,224,889
1972	5,228	131,300	217,351	31,809	4,857	13,575	404,120	2,629,009
1973	5,704	346,000	118,359	57,037	2,834	48,212	578,146	3,207,155
1974	23,904	6,600	143,656	12,773	3,229	13,557	203,719	3,410,874
1975	18,388	11,600	289,570	113,341	6,103	17,428	456,430	3,867,304
1976	4,493	1,200	211,359	104,306	7,744	90,205	419,307	4,286,611
1977	23,811	900	267,063	7,465	11,147	390,121	700,507	4,987,118
1978	5,685	700		235,548	2,547	652,061	896,541	5,883,659
1979	8,897	400		164,787		314,938	489,022	6,372,681
1980	148,312	300		41,031		143,502	333,145	6,705,826
1981	52,214	229		43,905		183,744	280,092	6,985,918
1982	80,929	293		59,007		273,962	414,191	7,400,109
1983	1,356	255		120,534		383,450	505,595	7,905,704
1984	544	25		215,286		385,079	600,934	8,506,638
1985	453	39		287,849		460,571	748,912	9,255,550
1986	672	13		116,960		116,094	233,739	9,489,289
1987	11,101	0		47,484		210,966	269,551	9,758,840
1988	8,690	0		32,067		218,901	259,658	10,018,498
1989[e]	42,678	0		99,056		725,164	866,898	10,885,396
Total	517,660	1,266,654	2,400,690	1,994,505	60,206	4,645,681		10,885,396

[a]For a summary of historical additions (1962–1984), see Table 4.6 in ref. 3. For operating sites (Beatty, Richland, and Barnwell), the additions for 1985–1987 are from ref. 6 and for 1988–1989 are from ref. 7.

[b]West Valley includes a commercial state-licensed facility which opened Nov. 18, 1963, and closed Mar. 11, 1975, and an NRC-licensed facility (for on-site fuel reprocessing wastes) which opened in 1966 and continued to receive only on-site generated LLW associated with water treatment and site cleanup until late 1986. This license is in abeyance. Disposal operations at the West Valley Demonstration Project (WVDP) have been suspended pending the preparation of an EIS report for the West Valley site closure. The WVDP began in 1982. The LLW radioactivity reported for 1982 through 1986 are for the WVDP only and are taken from ref. 5. Since the beginning of 1987, LLW generated at the WVDP is stored on-site in engineered facilities pending final disposal (ref. 8).

[c]Closed Dec. 27, 1977.

[d]Closed Apr. 8, 1978.

[e]The 1989 annual radioactivity of 866,898 Ci is almost twice the value of 454,000 Ci predicted for 1989 in Table 4.2 of last year's report (DOE/RW-0006, Rev. 5). These annual radioactivity and volume values (see Table 4.10) are larger than expected. Investigation by DOE's National Low-Level Waste Management Program determined that these larger values are due to normal power plant 10-year maintenance outages.

Table 4.12. Distribution of total volume and radioactivity, by state, of LLW shipped to commercial disposal sites in 1989[a]

State	Volume (m^3)	Radioactivity (Ci)	State	Volume (m^3)	Radioactivity (Ci)
Alabama	1,394	1,165	Nebraska	473	328
Alaska	<1	4	Nevada	9	789
Arizona	899	1,123	New Hampshire	<1	27
Arkansas	226	322	New Jersey	1,516	317,833
California	3,340	9,949	New Mexico	39	95
Colorado	248	1,103	New York	2,744	101,453
Connecticut	1,390	21,885	North Carolina	1,654	7,390
Delaware	39	2	North Dakota	3	2
District of Columbia	26	1	Ohio	1,667	1,211
Florida	999	2,624	Oklahoma	910	4
Georgia	1,266	2,887	Oregon	2,149	466
Hawaii	176	7	Pennsylvania	3,667	78,347
Idaho	4	2	Puerto Rico	0	0
Illinois	3,817	147,115	Rhode Island	40	23
Indiana	61	63	South Carolina	2,738	2,432
Iowa	171	16,953	South Dakota	<1	<1
Kansas	180	2,471	Tennessee	3,369	3,044
Kentucky	285	21	Texas	627	11,357
Louisiana	615	1,478	Utah	178	8
Maine	443	274	Vermont	5	2
Maryland	1,133	648	Virgin Islands	0	0
Massachusetts	1,601	57,386	Virginia	2,346	3,053
Michigan	1,220	7,186	Washington	748	1,105
Minnesota	622	60,952	West Virginia	12	23
Mississippi	311	222	Wisconsin	195	1,075
Missouri	532	793	Wyoming	<1	<1
Montana	3	1	Other[b]	5	193
			Total	46,095[c]	866,898[c]

[a]Data provided by EG&G, Idaho (ref. 7), to be published by the Low-Level Waste Management Program.
[b]Wastes generated by U.S. Army bases located inside and outside the United States.
[c]Differences in the 1989 annual totals (i.e., the volume in Table 4.10 and the radioactivity in Table 4.11 and the summations of shipments by state, as shown above) result from rounding off and truncation of numbers.

Table 4.13. 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. 15 and 17.

Table 4.14. Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from I/I activities[a,b]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[c]	Annual rate	Accumulation
1980	40.2	478	232	3,769	520.5	661
1981	34.7	513	191	3,733	429.5	938
1982	26.5	539	168	3,682	377.8	1,201
1983	30.4	569	125	3,596	281.3	1,406
1984	27.1	597	134	3,530	300.9	1,682
1985	30.2	627	175	3,511	392.1	2,068
1986	19.7	646	64	3,380	143.7	2,202
1987	20.4	667	50	3,256	111.6	2,394
1988	12.1	679	46	3,138	102.8	2,603
1989	12.4	691	47	3,029	105.7	2,827
1990	12.1	703	46	2,926	102.7	3,052
1991	12.1	716	46	2,829	102.7	3,278
1992	12.1	728	46	2,739	102.7	3,504
1993	12.1	740	46	2,654	102.7	3,728
1994	12.1	752	46	2,574	102.7	3,950
1995	12.1	764	46	2,499	102.7	4,169
1996	12.1	776	46	2,429	102.7	4,385
1997	12.1	788	46	2,364	102.7	4,597
1998	12.1	800	46	2,302	102.7	4,807
1999	12.1	812	46	2,245	102.7	5,014
2000	12.1	824	46	2,191	102.7	5,218
2001	12.1	837	46	2,141	102.7	5,420
2002	12.1	849	46	2,094	102.7	5,619
2003	12.1	861	46	2,050	102.7	5,816
2004	12.1	873	46	2,010	102.7	6,012
2005	12.1	885	46	1,972	102.7	6,205
2006	12.1	897	46	1,937	102.7	6,397
2007	12.1	909	46	1,904	102.7	6,587
2008	12.1	921	46	1,874	102.7	6,776
2009	12.1	933	46	1,846	102.7	6,964
2010	12.1	945	46	1,820	102.7	7,151
2011	12.1	958	46	1,796	102.7	7,337
2012	12.1	970	46	1,774	102.7	7,521
2013	12.1	982	46	1,754	102.7	7,705
2014	12.1	994	46	1,735	102.7	7,888
2015	12.1	1,006	46	1,718	102.7	8,071
2016	12.1	1,018	46	1,703	102.7	8,253
2017	12.1	1,030	46	1,689	102.7	8,434
2018	12.1	1,042	46	1,677	102.7	8,615
2019	12.1	1,054	46	1,666	102.7	8,795
2020	12.1	1,066	46	1,656	102.7	8,975

[a]The reported total volume and undecayed radioactivity shipped for commercial disposal during 1962–1989 (Tables 4.10 and 4.11) are comprised of fuel cycle and non-fuel cycle LLW. The I/I annual volume and radioactivity for each year are obtained from the total volume and radioactivity of LLW for the year by subtracting the fuel cycle LLW volume and radioactivity for that year from the reported annual LLW total. Although Tables 4.15–4.19 for LLW fuel cycle waste show 1980 as a beginning, the computer-generated tables from which they are taken go back to 1962. These historically complete tables are used in conjunction with Tables 4.10 and 4.11 to determine annual I/I additions.

[b]The projected volume of I/I waste is assumed to remain constant from 1990 through 2020 (see ref. 21 for rationale). The radioactivity associated with this volume is calculated using the composition given in Table A.11 of Appendix A.

[c]The radioactivity added each year is decayed as if it had the composition given in Table A.11 of Appendix A.

Table 4.15. Historical and projected volume, radioactivity, and thermal power of routine LLW shipped for disposal from BWRs[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	26.1	141	41	128	314	1,104
1981	23.0	164	42	144	318	1,254
1982	25.5	190	38	155	285	1,351
1983	22.6	212	56	183	425	1,579
1984	24.4	237	29	178	220	1,565
1985	23.1	260	28	177	210	1,555
1986	17.3	277	32	182	240	1,582
1987	14.3	292	28	183	214	1,580
1988	11.7	303	29	185	217	1,584
1989	14.2	317	32	190	240	1,611
1990	10.3	328	54	216	403	1,798
1991	10.4	338	54	236	406	1,952
1992	10.4	349	54	252	404	2,083
1993	10.4	359	54	266	407	2,199
1994	10.4	369	54	278	405	2,298
1995	10.4	380	54	290	407	2,388
1996	10.5	390	54	300	408	2,468
1997	10.5	401	54	310	409	2,540
1998	10.6	411	55	319	412	2,607
1999	10.6	422	55	327	411	2,666
2000	10.6	433	55	335	412	2,720
2001	10.6	443	55	343	414	2,769
2002	10.7	454	55	350	416	2,815
2003	10.7	465	56	357	417	2,858
2004	10.8	475	56	364	419	2,897
2005	10.8	486	56	370	421	2,935
2006	10.8	497	56	377	422	2,970
2007	10.9	508	57	383	424	3,003
2008	10.9	519	57	389	426	3,035
2009	10.8	530	56	394	422	3,059
2010	10.4	540	54	397	405	3,065
2011	9.4	549	49	395	368	3,035
2012	8.8	558	46	391	341	2,986
2013	8.1	566	42	386	316	2,922
2014	6.2	573	32	373	241	2,794
2015	6.2	579	32	364	241	2,690
2016	5.7	584	29	354	220	2,580
2017	5.7	590	29	346	220	2,487
2018	5.4	595	28	339	210	2,396
2019	5.4	601	28	332	208	2,316
2020	5.3	606	28	327	208	2,247

[a]Annual volume and radioactivity additions through 1989 are reported values (refs. 6, 18, and 19). Beginning in 1990, these values are calculated using the energy values presented in Table A.8 and the source term (which describes routine waste) shown in Fig. A.6 of Appendix A.

[b]The radioactivity added each year is decayed as if it had the composition given in Fig. A.6 of Appendix A.

Table 4.16. Historical and projected volume, radioactivity, and thermal power of routine LLW shipped for disposal from PWRs[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	22.4	124	24	81	160	496
1981	22.8	147	31	102	207	616
1982	20.8	168	34	122	224	732
1983	21.4	189	32	138	211	817
1984	21.0	210	41	163	275	958
1985	18.7	229	29	171	190	989
1986	11.6	241	22	175	144	982
1987	12.2	253	25	184	166	1,008
1988	10.9	264	36	203	238	1,103
1989	13.4	277	48	231	321	1,258
1990	8.4	285	46	253	300	1,361
1991	8.6	294	47	276	307	1,464
1992	8.8	303	49	298	314	1,563
1993	8.9	312	49	320	318	1,655
1994	8.9	321	49	340	318	1,737
1995	9.1	330	50	361	324	1,817
1996	9.1	339	50	380	326	1,890
1997	9.2	348	51	399	327	1,959
1998	9.3	357	51	418	330	2,024
1999	9.2	367	51	436	330	2,083
2000	9.3	376	51	454	333	2,140
2001	9.4	385	52	471	336	2,195
2002	9.4	395	52	488	336	2,246
2003	9.5	404	52	505	339	2,296
2004	9.5	414	53	522	340	2,344
2005	9.6	423	53	538	342	2,389
2006	9.6	433	53	554	343	2,432
2007	9.6	443	53	569	342	2,471
2008	9.6	452	53	584	341	2,507
2009	9.7	462	53	598	345	2,545
2010	9.7	472	54	613	347	2,582
2011	9.3	481	51	625	333	2,602
2012	9.1	490	50	636	323	2,614
2013	8.1	498	45	642	289	2,595
2014	7.3	505	40	645	260	2,557
2015	6.9	512	38	647	247	2,517
2016	6.3	519	35	646	225	2,464
2017	5.9	525	32	645	210	2,408
2018	5.8	530	32	644	206	2,359
2019	5.7	536	32	643	205	2,317
2020	5.3	541	29	641	187	2,264

[a]Annual volume and radioactivity additions through 1989 are reported values (refs. 6, 18, and 19). Beginning in 1990, these values are calculated using the energy values presented in Table A.8 and the source term (which describes routine waste) shown in Fig. A.7 of Appendix A.

[b]The radioactivity added each year is decayed as if it had the composition given in Fig. A.7 of Appendix A.

Table 4.17. Historical and projected volume, radioactivity, and thermal power of nonroutine LLW shipped for disposal from LWRs[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	0.73	3.9	36	569	328	5,741
1981	0.16	4.1	16	504	138	5,153
1982	0.47	4.5	175	610	1,652	6,157
1983	0.16	4.7	292	816	2,686	8,056
1984	0.26	4.9	397	1,083	3,609	10,562
1985	0.30	5.2	518	1,422	4,887	13,966
1986	0.04	5.3	116	1,322	1,091	13,222
1987	0.05	5.3	167	1,302	1,543	13,086
1988	0.02	5.4	149	1,268	1,389	12,801
1989	0.20	5.6	740	1,834	6,902	18,076
1990	0.57	6.1	353	1,905	2,938	18,589
1991	0.57	6.7	357	1,985	2,971	19,155
1992	0.58	7.3	358	2,056	2,979	19,665
1993	0.58	7.8	361	2,122	3,004	20,139
1994	0.58	8.4	360	2,180	2,995	20,546
1995	0.58	9.0	362	2,234	3,016	20,925
1996	0.59	9.6	364	2,285	3,027	21,268
1997	0.59	10.2	365	2,331	3,037	21,580
1998	0.59	10.8	368	2,376	3,062	21,878
1999	0.59	11.4	367	2,417	3,057	22,135
2000	0.60	12.0	369	2,456	3,070	22,374
2001	0.60	12.6	371	2,494	3,087	22,602
2002	0.60	13.2	372	2,531	3,099	22,813
2003	0.60	13.8	374	2,566	3,111	23,011
2004	0.61	14.4	375	2,600	3,124	23,198
2005	0.61	15.0	377	2,634	3,137	23,375
2006	0.61	15.6	378	2,667	3,151	23,544
2007	0.61	16.2	379	2,698	3,157	23,699
2008	0.61	16.8	380	2,729	3,166	23,846
2009	0.61	17.4	378	2,755	3,150	23,958
2010	0.60	18.0	369	2,771	3,068	23,975
2011	0.55	18.6	340	2,758	2,828	23,752
2012	0.52	19.1	319	2,731	2,659	23,394
2013	0.48	19.6	293	2,686	2,438	22,866
2014	0.39	20.0	236	2,594	1,961	21,935
2015	0.38	20.4	231	2,517	1,926	21,099
2016	0.35	20.7	211	2,435	1,759	20,204
2017	0.34	21.0	207	2,363	1,720	19,388
2018	0.33	21.4	199	2,297	1,653	18,611
2019	0.32	21.7	197	2,241	1,642	17,921
2020	0.31	22.0	192	2,189	1,599	17,275

[a]Annual volume and radioactivity additions through 1989 are reported values (refs. 6, 18, and 19). Beginning in 1990, these values are calculated using the energy values presented in Table A.8 and the source terms (which describe nonroutine waste) shown in Figs. A.6 (BWRs) and A.7 (PWRs) of Appendix A.

[b]The radioactivity added each year is decayed as if it had the composition given in Figs. A.6 (BWRs) and A.7 (PWRs) of Appendix A.

Table 4.18. Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from UF_6 conversion for LWRs[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power[c] (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	0.45	4.2	0.0003	0.003	0.005	0.05
1981	0.49	4.7	0.0004	0.004	0.006	0.06
1982	0.64	5.4	0.0005	0.004	0.008	0.06
1983	0.73	6.1	0.0006	0.005	0.009	0.07
1984	0.65	6.8	0.0005	0.005	0.008	0.08
1985	0.91	7.7	0.0007	0.006	0.011	0.09
1986	0.63	8.3	0.0005	0.007	0.007	0.10
1987	0.92	9.2	0.0007	0.007	0.011	0.11
1988	0.77	10.0	0.0006	0.008	0.009	0.12
1989	0.81	10.8	0.0006	0.008	0.009	0.13
1990	0.57	11.4	0.0004	0.009	0.007	0.13
1991	0.92	12.3	0.0007	0.010	0.011	0.14
1992	0.63	12.9	0.0005	0.010	0.007	0.15
1993	0.81	13.7	0.0006	0.011	0.010	0.16
1994	0.82	14.5	0.0006	0.011	0.010	0.17
1995	0.74	15.3	0.0006	0.012	0.009	0.18
1996	0.81	16.1	0.0006	0.013	0.010	0.19
1997	0.75	16.9	0.0006	0.013	0.009	0.20
1998	0.81	17.7	0.0006	0.014	0.009	0.21
1999	0.83	18.5	0.0006	0.014	0.010	0.22
2000	0.80	19.3	0.0006	0.015	0.009	0.23
2001	0.79	20.1	0.0006	0.016	0.009	0.24
2002	0.81	20.9	0.0006	0.016	0.009	0.25
2003	0.78	21.7	0.0006	0.017	0.009	0.25
2004	0.84	22.5	0.0006	0.017	0.010	0.26
2005	0.79	23.3	0.0006	0.018	0.009	0.27
2006	0.81	24.1	0.0006	0.019	0.010	0.28
2007	0.82	24.9	0.0006	0.019	0.010	0.29
2008	0.83	25.8	0.0006	0.020	0.010	0.30
2009	0.82	26.6	0.0006	0.021	0.010	0.31
2010	0.80	27.4	0.0006	0.021	0.009	0.32
2011	0.65	28.0	0.0005	0.022	0.008	0.33
2012	0.75	28.8	0.0006	0.022	0.009	0.34
2013	0.54	29.3	0.0004	0.023	0.006	0.34
2014	0.54	29.9	0.0004	0.023	0.006	0.35
2015	0.57	30.4	0.0004	0.023	0.007	0.36
2016	0.45	30.9	0.0003	0.024	0.005	0.36
2017	0.46	31.3	0.0004	0.024	0.005	0.37
2018	0.45	31.8	0.0003	0.024	0.005	0.37
2019	0.44	32.2	0.0003	0.025	0.005	0.38
2020	0.39	32.6	0.0003	0.025	0.005	0.38

[a]These values are calculated based on the UF_6 conversion demand needed to support the electrical generation shown in Table A.8 of Appendix A and the assumption that the settling pond sludges from the direct-fluorination process (Fig. A.2 of Appendix A) are the only LLW thus far shipped for commercial disposal.

[b]The radioactivity added each year is decayed as if it had the composition given in Fig. A.2 of Appendix A.

[c]These values are small since the radionuclides involved have low energy per disintegration; however, they are presented in the interest of completeness.

Table 4.19. Historical and projected volume, radioactivity, and thermal power of LLW shipped for disposal from fuel fabrication for LWRs[a]

End of calendar year	Volume (10^3 m^3)		Radioactivity (10^3 Ci)		Thermal power[c] (W)	
	Annual rate	Accumulation	Annual rate	Accumulation[b]	Annual rate	Accumulation
1980	2.4	17	0.006	0.05	0.16	1.1
1981	2.6	19	0.006	0.06	0.17	1.3
1982	2.6	22	0.006	0.07	0.18	1.5
1983	2.7	25	0.006	0.08	0.18	1.7
1984	3.0	28	0.007	0.09	0.20	1.9
1985	3.6	31	0.009	0.10	0.24	2.1
1986	3.9	35	0.009	0.11	0.26	2.4
1987	4.3	39	0.010	0.12	0.29	2.7
1988	4.9	44	0.012	0.14	0.33	3.0
1989	5.1	49	0.012	0.15	0.34	3.4
1990	5.2	55	0.012	0.17	0.35	3.8
1991	5.3	60	0.013	0.19	0.36	4.1
1992	5.4	65	0.013	0.20	0.36	4.5
1993	5.4	71	0.013	0.22	0.36	4.9
1994	5.4	76	0.013	0.24	0.36	5.2
1995	5.5	82	0.013	0.26	0.37	5.6
1996	5.5	87	0.013	0.27	0.37	6.0
1997	5.6	93	0.013	0.29	0.37	6.4
1998	5.6	98	0.013	0.31	0.38	6.8
1999	5.6	104	0.013	0.33	0.37	7.2
2000	5.6	110	0.013	0.35	0.38	7.6
2001	5.7	115	0.013	0.36	0.38	7.9
2002	5.7	121	0.014	0.38	0.38	8.3
2003	5.7	127	0.014	0.40	0.38	8.7
2004	5.7	132	0.014	0.42	0.38	9.1
2005	5.8	138	0.014	0.44	0.39	9.5
2006	5.8	144	0.014	0.46	0.39	9.9
2007	5.8	150	0.014	0.47	0.39	10.3
2008	5.8	156	0.014	0.49	0.39	10.7
2009	5.8	161	0.014	0.51	0.39	11.1
2010	5.8	167	0.014	0.53	0.39	11.5
2011	5.4	173	0.013	0.55	0.36	11.9
2012	5.2	178	0.012	0.56	0.35	12.3
2013	4.7	182	0.011	0.58	0.31	12.6
2014	4.0	186	0.010	0.59	0.27	12.9
2015	3.9	190	0.009	0.60	0.26	13.1
2016	3.5	194	0.008	0.62	0.24	13.4
2017	3.4	197	0.008	0.63	0.23	13.6
2018	3.3	200	0.008	0.64	0.22	13.8
2019	3.2	204	0.008	0.65	0.22	14.0
2020	3.1	207	0.007	0.66	0.20	14.3

[a]Calculated using the energy values presented in Table A.8 and the source term (which describes fuel fabrication waste) in Fig. A.5 of Appendix A.

[b]The radioactivity added each year is decayed as if it had the composition given in Fig. A.5 of Appendix A.

[c]These values are small since the radionuclides involved have low energy per disintegration; however, they are presented in the interest of completeness.

ORNL-PHOTO 3009-87

Photo 5.1. An aerial view of the Homestake Partners Mill at Ambrosia Lake, New Mexico. (Courtesy of the U.S. Department of Energy, Energy Information Administration, Washington, D.C.)

5. URANIUM MILL TAILINGS FROM COMMERCIAL OPERATIONS

5.1 INTRODUCTION

Uranium mill tailings are the residual wastes of milled ore that remain after the uranium values have been recovered. Mill tailings at licensed sites and those that will be produced to meet future uranium requirements are "commercial" mill tailings, the subject of this chapter. Tailings resulting from uranium mined for defense purposes are not included. Existing tailings at sites that are no longer licensed are classified as "inactive" mill tailings. Inactive tailings are administered under the remedial action projects discussed in Chapter 6.

Mill tailings are generated during the process of extracting uranium from the ore fed to the mill. Uranium mills employ either an acid leach or an alkaline leach process to recover uranium, depending on the ore's chemical characteristics. Currently, more than 80% of the U.S. milling capacity uses the acid leach process. Mill tailings from both processes consist of slurries of sands and clay-like particles called slimes; the tailings slurries are pumped to tailings impoundment ponds for disposal.

U.S. uranium production from conventional milling has declined since 1980, and, as a consequence, the quantity of mill tailings generated each year has declined (see Table 5.1). During 1989, four mills operated and generated tailings. The location of each of these mills is indicated in the map of Fig. 5.1. At the end of 1989, three conventional mills were operating in the United States,[1,2] capable of processing a total of 7,170 t of uranium ore per day. These three mills represent about 26% of the total available domestic conventional uranium milling capacity.[1,2] This small utilization of U.S. capacity can be attributed in large part to nuclear power plant cancellations and deferments. Since the late 1970s, these have led to lower uranium demand. This, in turn, has contributed to lower uranium prices and a steady decline in domestic uranium mining. In addition, cost increases for domestic uranium mining and milling have led to increased reliance on lower cost imported uranium.

In recent years, U.S. uranium concentrate production has been from conventional milling of ore; processing of solutions from in situ leach mining, heap-leach solutions, mine water, and other solutions; and as by-product uranium from the processing of phosphate and copper ores.

In 1989, the total processing of ore at conventional mills was 17% more than in 1988. Concentrate production in 1989 was about 3,700 t U_3O_8, about 500 t above 1988 production.[2] Nonconventional concentrate production in 1989 decreased to about 2,600 t U_3O_8, or 7% below 1988 production.[2] In situ leaching (ISL) technology has been increasingly applied in recent years in mining operations. Of the total economic reserves reported annually to the EIA, the amount for which ISL is the proposed mining method has increased from 28% in 1984 to 58% in 1989. Because ISL mining generally is successful at lower costs compared with conventional mining methods, it could gain even wider use in the near future. ISL and by-product production methods do not generate mill tailings. Residual wastes from nonconventional methods are not considered in this section.

The volumes of historical and projected cumulative mill tailings through the year 2005 are shown in Fig. 5.2. This graph is based on the data reported in Table 5.1. The estimates of projected domestic tailings are based on the DOE/EIA uranium mining and milling viability assessment report (ref. 3), as well as ref. 4.

5.2 INVENTORIES

The status of the licensed mills, including their estimated commercial and government-related tailings inventories at the end of 1989, is shown in Table 5.2 (data based on refs. 1–13). For each mill, the amount of tailings generated depends on the amount of ore processed, the ore-feed grade (U_3O_8 assay), and the percentage of U_3O_8 recovered. Table 5.3 lists the annual milling rate, ore grade, and U_3O_8 recovery; the associated mill tailings generated through 1989 are 188×10^6 t (124×10^6 m^3). The DOE/EIA estimates[1] that 1.13×10^6 t (7.00×10^5 m^3) of tailings were added to the tailings piles at operating mill sites during 1989.

5.3 WASTE CHARACTERIZATION

Because the amount of uranium (by weight) extracted from the ore during milling is relatively small,

Fig. 5.1. Locations of uranium mill tailings sites active during at least part of 1989.

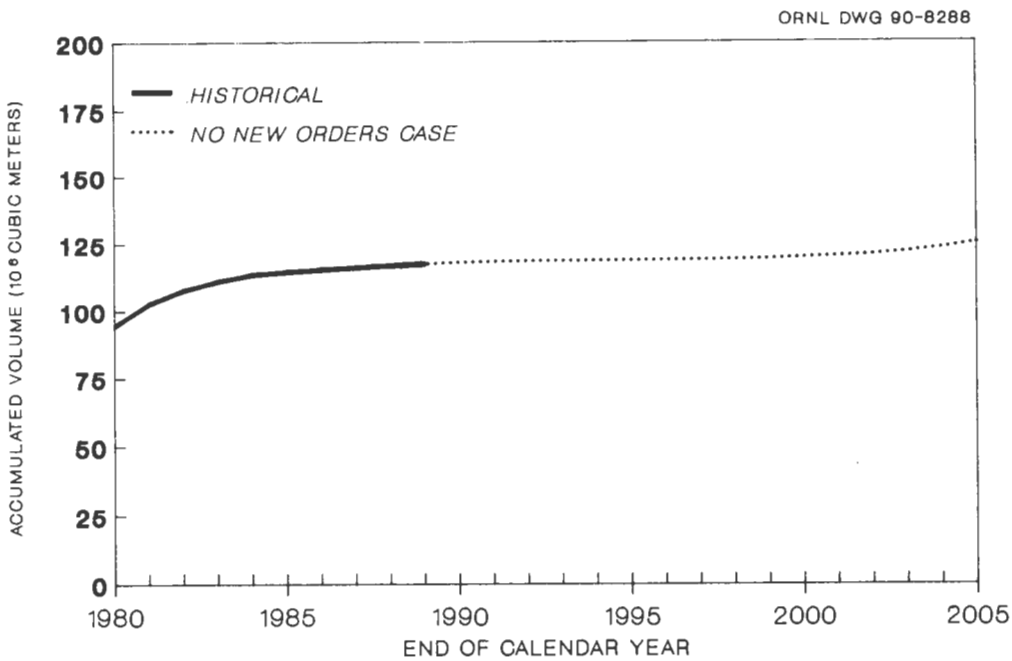

Fig. 5.2. Historical and projected accumulated volume of commercial mill tailings.

the dry weight of the tailings produced is nearly equal to the dry weight of ore processed. Dry tailings typically are composed of 70 to 80 wt % sand-sized particles and 20 to 30 wt % finer-sized particles. Acid leaching is preferred for ores with low lime content (12% or less). Those with high lime content require excessive quantities of acid for neutralization and, for economic reasons, are best treated by alkaline leaching. In either leach process, most of the uranium is dissolved, together with other materials present in the ore (e.g., iron, aluminum, and other impurities). After the ore is leached, the uranium-laden leach liquor is removed from the tailings solids by decantation. After thorough washing, the tailings are pumped as a slurry to a tailings pond. The waste liquid accompanying the tailings solids to the disposal pond is approximately 1 to 1.5 times the weight of the processed ore. Typical characteristics of the tailings solids and liquid are outlined in Table 5.4 (ref. 10).

In August 1986, the EPA issued its final rules on ^{222}Rn emissions from tailings piles.[9] Mill owners have 6 years (subject to certain extensions) to phase out use of large existing tailings piles. New tailings piles must be contained in small [i.e., less than 16-ha (40-acre)] impoundments or disposed of by continuous dewatering and burial with no more than 4 ha (10 acres) uncovered at any one time.

5.4 PROJECTIONS

An average tailings density of 1.6 t/m^3 was used in projecting volumes of mill tailings through the year 2005 (Table 5.1). Projections of mill tailings were calculated based on the uranium requirements associated with the DOE/EIA 1989 No-New-Orders-Case nuclear growth scenario.[4] These projections assume a lead time of 2 years for mining/milling of uranium until its use as reactor fuel. The projected annual accumulations (Table 5.1) account only for tailings produced in filling U.S. utility requirements and export commitments by domestic producers. Tailings produced in filling potential DOE requirements for uranium are not included, because the amount would be minor in comparison with the commercial requirements.

The sum of the projected annual generated volume of uranium mill tailings from 1990 through 2000 is somewhat less than that was shown in the previous year's report. This may be attributed to the anticipated closing of several underground operations in that period, and with less ore to be processed, fewer tailings will be generated. As market prices edge upwards in the 2000 through 2005 period, conventional mining could again become economically feasible. This is reflected by an increase in the generation of tailings in that period.

5.5 REFERENCES

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12. U.S. Congress, House of Representatives, Committees on Energy and Commerce, Interior and Insular Affairs, Science, Space, and Technology, and Ways and Means, Uranium Revitalization, Tailings Reclamation and Enrichment Act of 1988: Hearing on H.R. 4489, 100th Congress, 2nd sess., Apr. 28, 1988, pp. 19–21.

13. Paul Estey, Exxon Coal and Minerals Company, Houston, Texas, telephone call to L. L. Smith, Energy Information Administration, Washington, D.C., regarding status of reclamation of Ray Point mill site and Felder mine site, Aug. 22, 1988.

Table 5.1. Historical and projected volume of uranium mill tailings[a,b,c]

End of calendar year	Volume (10^6 m^3) Annual	Accumulation
Prior to 1978		68.0
1978	7.9	75.8
1979	9.1	84.9
1980	9.5	94.4
1981	8.2	102.7
1982	5.0	107.7
1983	3.4	111.1
1984	2.5	113.6
1985	1.0	114.6
1986	0.7	115.4
1987	0.8	116.2
1988	0.7	116.9
1989	0.7	117.6
1990	0.6	118.2
1991	0.3	118.5
1992	0.2	118.7
1993	0.1	118.8
1994	0.1	118.9
1995	0.1	119.0
1996	0.1	119.1
1997	0.1	119.2
1998	0.1	119.3
1999	0.3	119.6
2000	0.5	120.1
2001	0.5	120.6
2002	0.5	121.1
2003	1.0	122.1
2004	1.4	123.5
2005	1.9	125.4

[a]Projections are estimates of domestic tailings generated in support of the DOE/EIA Reference-Case nuclear growth scenario described in ref. 3, which is the No-New-Orders Case of ref. 4.

[b]This table has been revised based on a detailed study of milling data from the Grand Junction Project Office and EIA files.

[c]Sources: Prior to 1984 – U.S. Department of Energy, Grand Junction Project Office data files. 1984-1989 – Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey."

Table 5.2. Status of conventional uranium mill sites at the end of 1989[a]

Location	Operator	Rated capacity[b] (t ore/d)	Status: Operations[b]	Status: Tailings[c]	Tailings storage area (ha)[d]	Total tailings: Volume[e] (10^6 m^3)	Total tailings: Mass (10^6 t)	Total tailings: Government portion[f] (10^6 t)
Colorado								
Canon City	Cotter	1,090	Shut down 1987	Wood chip covering	81	1.3	2.1	0.3
Uravan	Umetco Minerals	1,180	Shut down 1984	Partially stabilized	44	5.9	9.5	5.2
Subtotal		2,270			125	7.2	11.6	5.5
New Mexico								
Cebolleta	Sohio Western Mining	1,450[g]	Decommissioned, 1986	h	73	1.2	1.9	0
Church Rock	United Nuclear	2,720[g]	Decommissioned, 1986	h	83	2.0	3.2	0
Grants	Anaconda	5,440[g]	Decommissioned, 1987	Partially stabilized	199	13.6	21.7	8.0
Grants	Quivira Mining	6,350	Shut down 1985	Fenced	142	18.8	30.1	9.1
Grants	Homestake Mining	3,080	Active	Unstabilized	105	12.7	20.3	10.4
Marquez	Bokum Resources	1,820[g]	New (on standby)	Never operated	0	0	0	0
Subtotal		9,430			602	48.3	77.2	27.5
South Dakota								
Edgemont	TVA	680[g]	Decommissioned, 1983	Partially stabilized	50	1.2	1.8	1.5
Subtotal		0			50	1.2	1.8	1.5
Texas								
Falls City	Continental Oil/ Pioneer Nuclear	3,080[g]	Decommissioned, 1981	h	89	6.5	10.5	0
Hobson	Chevron Resources	2,270	Active	h	101	3.4	5.4	0
Ray Point (Felder Facility)	Exxon	1,000[g]	Decommissioned, 1973[i]	Stabilized[j]	18	0.2	0.4[k]	0
Subtotal		2,270			208	10.2	16.2	0
Utah								
Blanding	Umetco/Energy Fuels Nuclear	1,810	Active	Partially stabilized	135	1.8	2.9	0
La Sal	Rio Algom	680	Shut down 1988	h	14	2.2	3.5	0
Moab	Atlas	1,270[g]	Decommissioning	Unstabilized	>80	6.0	9.6	5.4
Hanksville	Plateau Resources	910	New (on standby)	Never operated	28	0	0	0
Subtotal		3,400			>257	10.0	16.0	5.4
Washington								
Ford	Dawn Mining	410	Shut down 1982	Wood chip covering	43	1.8	2.8	1.1
Wellpinit	Western Nuclear	1,810	Shut down 1984	h	17	1.6	2.6	0
Subtotal		2,220			60	3.4	5.4	1.1

Table 5.2 (continued)

Location	Operator	Rated capacity[b] (t ore/d)	Status: Operations[b]	Status: Tailings[c]	Tailings storage area (ha)[d]	Total tailings: Volume[e] (10^6 m^3)	Total tailings: Mass (10^6 t)	Total tailings: Government portion[f] (10^6 t)
Wyoming								
Gas Hills	American Nuclear	860[g]	Decommissioned, 1988	Unstabilized	52	3.3	5.3	1.9
Gas Hills	Pathfinder	2,540	Shut down 1988	Unstabilized	55	6.6	10.6	2.4
Jeffrey City	Western Nuclear	1,540[g]	Decommissioned, 1988	Interim stabilization	34	4.4	7.0	3.0
Natrona	Umetco	1,270	Shut down 1984	Unstabilized	70	4.6	7.3	1.9
Powder River	Exxon	2,900[g]	Decommissioned, 1984	Partially stabilized	81	6.4	10.3	0
Powder River	Rocky Mountain Energy	1,810[g]	Decommissioned, 1987	Unstabilized	61	2.7	4.3	0
Shirley Basin	Pathfinder	1,630	Inactive Dec. 1988; resumed 1989	h	94	4.4	7.1	0
Shirley Basin	Petrotomics	1,360[g]	Decommissioned, 1985	Unstabilized	65	3.7	5.9	0.7
Red Desert	Minerals Exploration/ Union Energy Mining	2,720	Shut down May 1983	Partially stabilized	121	1.3	2.1	0
Subtotal		8,160			633	37.4	59.8	9.9
1989 total for all sites[b,l,m]		27,750			h	117.6	188.0	50.9[n]

[a]Data based on refs. 1-13. Note: subtotals and totals may not equal sum of components because of independent rounding. Ray Point, Texas (Felder Facility) site was stabilized during 1987 by Exxon Corporation. Historical data are revised based on detailed study of milling data from the Grand Junction Project Office and EIA files. The values shown include all tailings.

[b]From refs. 1, 7, and 11. Values rounded to nearest 10 t.

[c]On Aug. 15, 1986, EPA issued its final rules on ^{222}Rn emissions from tailings piles. Mill owners have 6 years (subject to certain extensions) to phase out the use of large existing tailings piles. New tailings piles may be contained in small impoundments (less than 16 ha) or disposed of continuously by dewatering and burial (i.e., no more than 4 ha are uncovered at any one time). See ref. 9.

[d]From ref. 8; 1 ha = 10,000 m^2 or approximately 2.5 acres.

[e]Calculated from reported mass using density = 1.6 t/m^3.

[f]From ref. 7, Table 8.0. These tailings are from government contracts only and are included in the "Total tailings" column.

[g]This capacity not available (see column labeled "Operations" under "Status" for reason). Estimates provided are not included in the total.

[h]Not available.

[i]From ref. 11.

[j]From ref. 13.

[k]From ref. 12.

[l]These values are cumulative totals that may not equal sum of components due to independent rounding. For annual totals see Table 5.3.

[m]From ref. 1.

[n]Total at the end of government-contracted deliveries in 1970 (ref. 7).

Table 5.3. Uranium ore processed, recovery rate, and tailings generated through 1989[a,b]

End of calendar year	Ore processed		U_3O_8 recovery from ore (%)	U_3O_8 product[d] (10^6 t)	Tailings generated	
	Mass[c] (10^6 t)	Grade (% U_3O_8)			Mass[e] (10^6 t)	Volume[f] (10^6 m^3)
Prior to 1978	g	g	g	g	108.8	68.0
1978	12.5	0.134	91	15.6	12.6	7.9
1979	14.6	0.113	91	15.3	14.5	9.1
1980	15.3	0.118	93	17.2	15.2	9.5
1981	13.2	0.115	94	14.5	13.2	8.2
1982	7.9	0.119	96	9.9	8.1	5.0
1983	5.4	0.128	97	7.0	5.4	3.4
1984	3.9	0.112	95	4.4	4.0	2.5
1985	1.6	0.161	96	2.8	1.6	1.0
1986	1.2	0.338	97	4.0	1.2	0.7
1987	1.3	0.284	96	3.8	1.3	0.8
1988	1.1	0.288	95	3.2	1.1	0.7
1989	1.1	0.323	95	3.7	1.0	0.7
Total[h]					188.0	117.6

[a]Sources: Prior to 1984 – U.S. Department of Energy, Grand Junction Area Office data files. 1984–1989 – Energy Information Administration, Form EIA-858, "Uranium Industry Annual Survey."

[b]This table has been revised based on a detailed study of milling data from the Grand Junction Project Office and EIA files. The values shown include all tailings.

[c]Before in-process inventory adjustments.

[d]Conventional U_3O_8 concentrate production.

[e]Includes adjustments to ore-fed amounts for annual mill circuit inventory changes and uranium concentrate production.

[f]Calculated assuming that the average density of tailings is 1.6 t/m^3 (metric tons per cubic meter).

[g]Not available.

[h]Totals may not equal sum of components due to independent rounding.

Table 5.4. Typical characteristics of uranium mill tailings[a]

Tailings component	Particle size (μm)	Chemical composition	Radioactivity characteristics
Sands	75 to 500	SiO_2 with <1% complex silicates of Al, Fe, Mg, Ca, Na, K, Se, Mn, Ni, Mo, Zn, U, and V; also metallic oxides	0.004 to 0.01% U_3O_8[b] Acid leaching:[c] 26 to 100 pCi ^{226}Ra/g; 70 to 600 pCi ^{230}Th/g
Slimes	45 to 75	Small amounts of SiO_2 but mostly very complex clay-like silicates of Na, Ca, Mn, Mg, Al, and Fe; also metallic oxides	U_3O_8 and ^{226}Ra are almost twice that in the sands Acid leaching:[c] 150 to 400 pCi ^{226}Ra/g; 70 to 600 pCi ^{230}Th/g
Liquids	d	Acid leaching: pH 1.2 to 2.0; Na^+, NH_4^+, SO_4^{-2}, Cl^-, and PO_4^{-3}; dissolved solids up to 1% Alkaline leaching: pH 10 to 10.5; CO_3^{-2} and HCO_3^-; dissolved solids ~10%	Acid leaching: 0.001 to 0.01% U 20 to 7,500 pCi ^{226}Ra/L; 2,000 to 22,000 pCi ^{230}Th/L Alkaline leaching: 200 pCi ^{226}Ra/L; essentially no ^{230}Th (insoluble)

[a]Adapted from information in ref. 10.

[b]U_3O_8 content is higher for acid leaching than for alkaline leaching.

[c]Separate analyses of sands and slimes from the alkaline leaching process are not available. However, total ^{226}Ra and ^{230}Th contents of up to 600 pCi/g (of each) have been reported for the combined sands and slimes.

[d]Particle size does not apply. Up to 70% of the liquid may be recycled. Recycle potential is greater in the alkaline process.

ORNL-PHOTO 6295-90

Photo 6.1. Transfer to a burial pit of the reactor vessel from the Ultra High Temperature Reactor Experiment (UHTREX) facility at Los Alamos National Laboratory. (Courtesy of the U.S. Department of Energy, Albuquerque Operations Office, Albuquerque, New Mexico.)

6. ENVIRONMENTAL RESTORATION WASTES

6.1 INTRODUCTION

The DOE Environmental Restoration Program is concerned with assessment and cleanup of inactive DOE facilities and sites contaminated by wastes from past nuclear operations. Most of the wastes from these restoration activities have very low radioactivity levels. They include TRU waste, various types of LLW, and uranium mill tailings. Some of the wastes from restoration activities that are under way or have been completed have been shipped to various disposal sites and are included in the inventories reported in Chapters 3–5. Low-level wastes from decommissioning commercial reactors and fuel cycle facilities are discussed in Chapter 7.

Environmental restoration activities are divided into two categories: remedial actions (RA), which is the major effort, and decontamination and decommissioning (D&D). Environmental restoration programs are proceeding in four major areas: (1) UMTRAP, (2) FUSRAP, (3) D&D Program, and (4) SFMP.

The UMTRAP activities are located in 11 states. Figures 6.1 and 6.2, respectively, show the projected volumes of mill tailings and other wastes from remaining UMTRAP activities in various states. The map in Fig. 6.3 locates UMTRAP sites within the states, most of which are in the Rocky Mountain region.

The FUSRAP sites are located in 13 states, and the projected volume of waste material remaining in each state is shown in Fig. 6.4. Most FUSRAP sites are in the eastern United States, as shown in Fig. 6.5. At the time of their use, these sites were active industrial areas that were conveniently located for storage and/or processing of imported ores and other radioactive materials.

The D&D Program activities are located in eight states. Mostly LLW and mill tailings will result from these activities, but some TRU wastes are also expected. Projected volumes of TRU wastes and LLW (including uranium mill tailings) from remaining D&D Program activities in various states are given in Figs. 6.6 and 6.7, respectively. The map in Fig. 6.8 indicates the specific locations of D&D Program sites.

The SFMP activities are found in 12 states. Primarily LLW and mill tailings will result from this program, but there will also be some TRU wastes. Projected volumes of TRU waste and projected volumes of LLW and mill tailings from remaining SFMP activities in various states are given in Figs. 6.9 and 6.10, respectively. Locations of the SFMP sites are indicated in Fig. 6.11.

The estimated total volumes of waste from the four environmental restoration program areas just described 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 REMEDIAL ACTIONS

6.2.1 Background and Scope

In addition to FUSRAP, which was formalized by DOE in 1977, and UMTRAP, which was authorized by Congress in 1978, DOE initiated an extensive remedial action survey and assessment program in 1987. This program, one portion of DOE's current Environmental Restoration and Waste Management Five-Year Plan, is primarily concerned with all aspects of the assessment and cleanup of inactive potential waste release sites located at DOE installations or at off-site locations under DOE management.[1] Its principal goal is to ensure that the potential risk to human health and safety and to the environment posed by contamination from inactive, uncontrolled, hazardous substance release sites is eliminated or reduced to acceptable levels. Efforts to meet requirements for improved remediation technologies, from site discovery through regulatory closeout, research and development, and technology demonstrations, are supported. Tasks are prioritized to ensure that those concerned with the greatest potential risks to human health and safety and to the environment are given first consideration in the allocation of program funds. The regulatory requirements for remedial action activities are prescribed primarily by the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA);[2] Sections 3004(u) and 3004(v) of the Resource Conservation and Recovery Act (RCRA);[3] the National Environmental Policy Act

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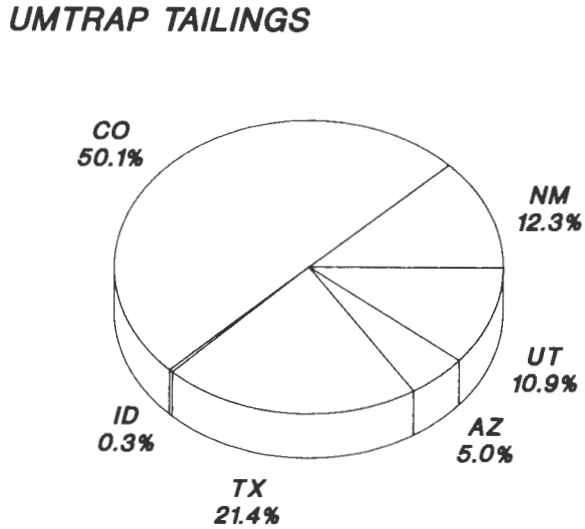
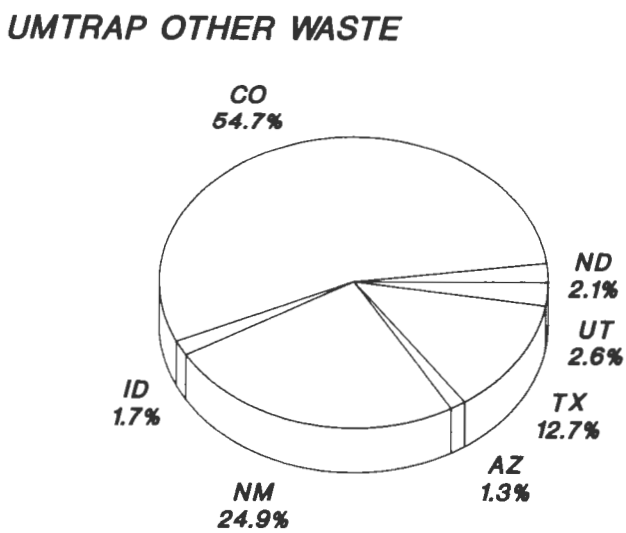


STATE	CUBIC METERS
AZ	8.26E+05
CO	8.26E+06
ID	4.59E+04
NM	2.03E+06
TX	3.53E+06
UT	1.79E+06
TOTAL	1.65E+07

Fig. 6.1. Projected total volumes of remaining mill tailings from UMTRAP activities in various states.

ORNL DWG 90-8290



STATE	CUBIC METERS
AZ	7.65E+04
CO	3.17E+06
ID	9.95E+04
NM	1.44E+06
ND	1.22E+05
TX	7.34E+05
UT	1.53E+05
TOTAL	5.79E+06

Fig. 6.2. Projected total volumes of remaining other wastes from UMTRAP activities in various states.

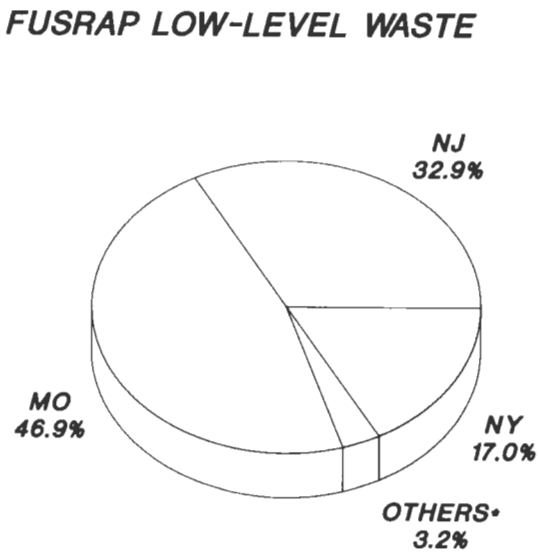
ORNL DWG 90A-641

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 COUNTY, 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.

ORNL DWG 90-8291



STATE	CUBIC METERS
CT*	1.90E+01
MA*	3.96E+03
MD*	2.75E+04
MI*	1.53E+02
MO	6.71E+05
NJ	4.71E+05
NY	2.44E+05
OR*	3.06E+02
PA*	2.90E+01
TN*	1.32E+04
TOTAL	1.43E+06

Fig. 6.4. Projected total volumes of remaining low-level wastes from FUSRAP activities in various states.

ORNL DWG 90-640

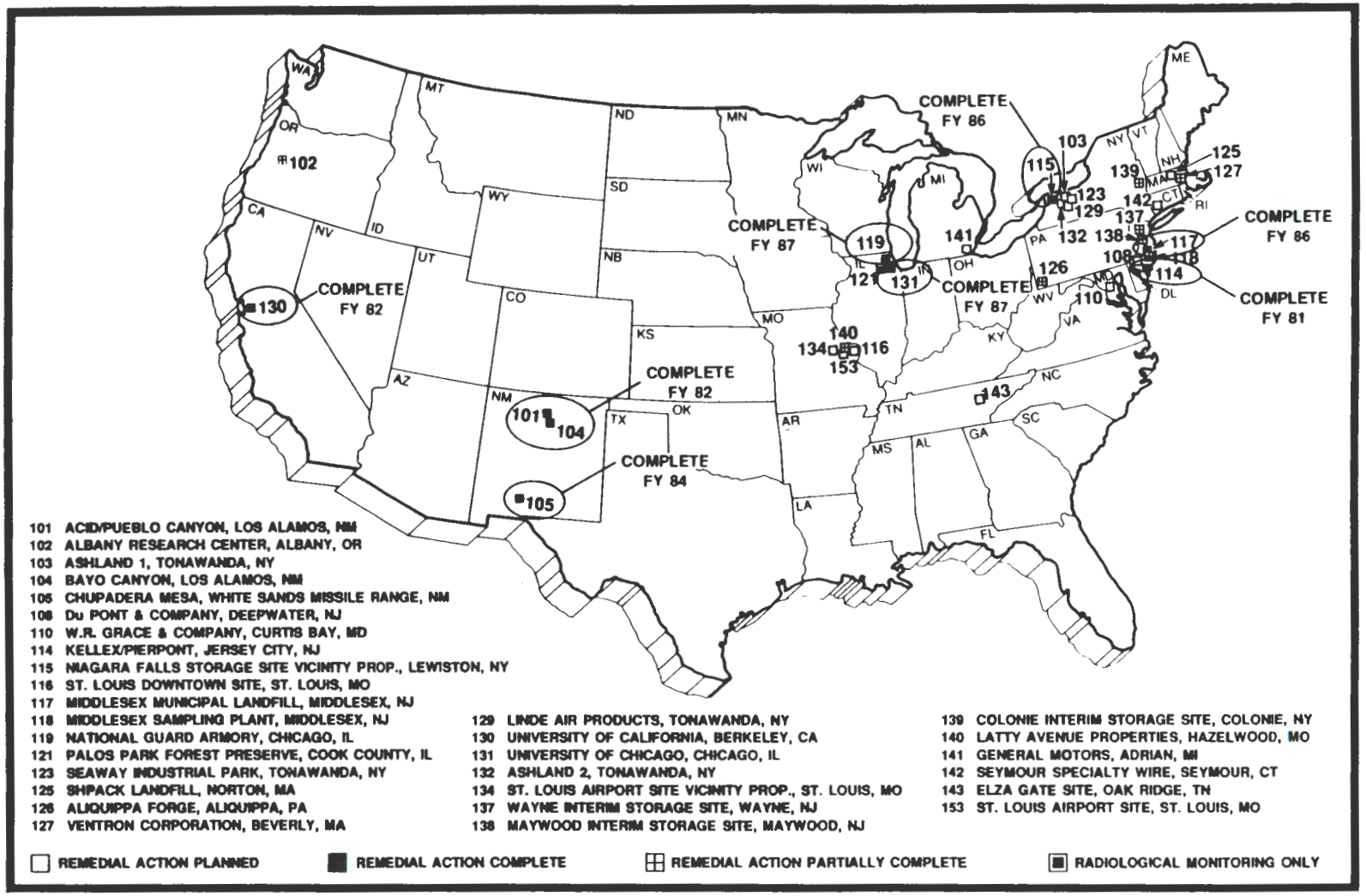
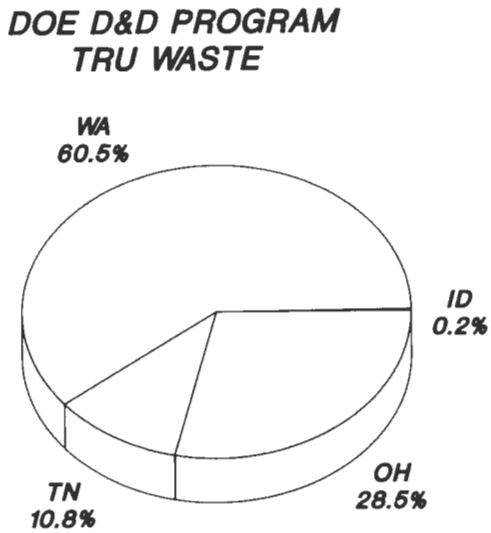


Fig. 6.5. Locations of FUSRAP sites.

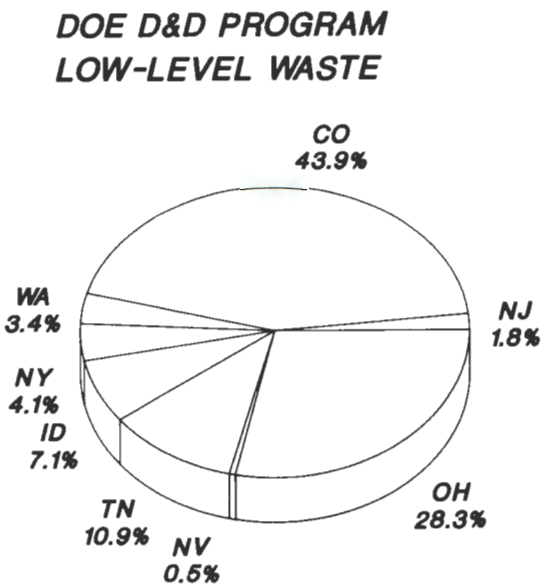
ORNL DWG 90-8292



STATE	CUBIC METERS
ID	1.00E+00
OH	1.58E+02
TN	6.00E+01
WA	3.36E+02
TOTAL	5.55E+02

Fig. 6.6. Projected total volumes of remaining TRU wastes from DOE D&D Program activities in various states.

ORNL DWG 90-8293

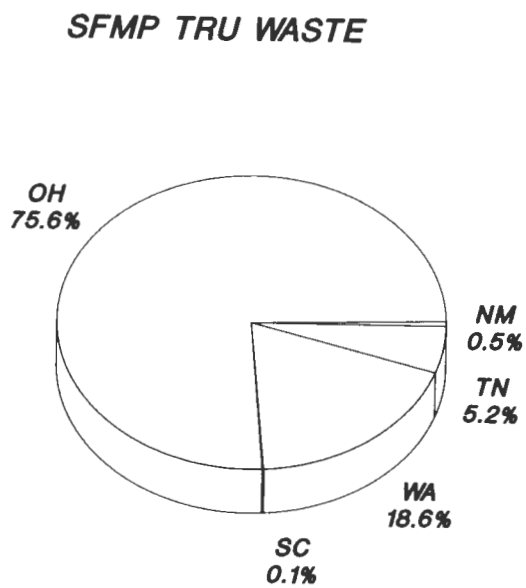


STATE	CUBIC METERS
CO	8.52E+04
ID	1.38E+04
NJ	3.52E+03
NV	1.00E+03
NY	7.92E+03
OH	5.50E+04
TN	2.12E+04
WA	6.55E+03
TOTAL	1.94E+05

Fig. 6.7. Projected total volumes of remaining low-level wastes from DOE D&D Program activities in various states.

Fig. 6.8. Locations of DOE D&D Program sites.

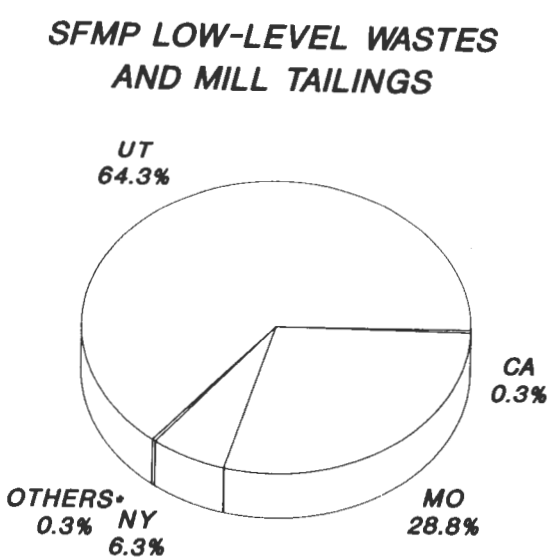
ORNL DWG 90-8295



STATE	CUBIC METERS
NM	1.10E+01
OH	1.83E+03
SC	3.00E+00
TN	1.25E+02
WA	4.52E+02
TOTAL	2.43E+03

Fig. 6.9. Projected total volumes of remaining TRU wastes from SFMP activities in various states.

ORNL DWG 90-8296



STATE	CUBIC METERS
CA	7.34E+03
ID*	1.08E+03
IL*	6.79E+02
MO	7.18E+05
NM*	6.05E+02
NY	1.58E+05
OH*	4.82E+03
SC*	4.50E+01
TN*	1.08E+03
UT	1.61E+06
WA*	1.80E+01
TOTAL	2.50E+06

Fig. 6.10. Projected total volumes of remaining low-level wastes and mill tailings from SFMP activities in various states.

Fig. 6.11. Locations of SFMP sites.

(NEPA);[4] and, with respect to radioactive substances, the Atomic Energy Act (AEA).[5] Certain state and local requirements are also applicable. Other requirements are set forth in various DOE Orders, standards, and other documents. The tasks associated with remedial actions encompass (1) site discovery, preliminary assessment, and site inspection; (2) site characterization, analysis of cleanup alternatives, and selection of remedy; (3) cleanup and site closure; and (4) site compliance monitoring. Although remedial actions may deal with surface water contamination or with tanks, buildings, or structures, most remedial action activities are concerned with contaminated soil and groundwater.

The remedial action portion of the Environmental Restoration and Waste Management Five-Year Plan includes plants and offices in 12 states assigned to 7 DOE/EM field offices. Projections of radioactive and mixed wastes from these activities are not yet available for this report.

6.2.2 Uranium Mill Tailings Remedial Action Program

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 remedial action as required on properties in the vicinity of the tailings sites.[6] Initial tasks under UMTRAP were to designate inactive uranium mill tailings sites for remedial action and to evaluate the economic viability of reprocessing tailings. The primary criterion for inclusion of mill tailings sites in UMTRAP was that the processing site must have had all or substantially all of the uranium produced for sales to any federal agency prior to January 1971. Evaluations of the economic viability of reprocessing showed the residual content of uranium and other metals in the tailings to be too low to make reprocessing worthwhile.

Twenty-four inactive uranium processing sites and associated vicinity properties located in ten states 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 area in Canonsburg, Pennsylvania. Engineering assessment and economic evaluation documents about each site have been published.[7]

Nine of the sites are identified as "high-priority," seven as "medium-priority," and eight as "low-priority" sites. To the extent practical, remedial action will be accomplished in order of these priorities. Table 6.2 gives the current remedial action status, duration schedules, and stored waste volume inventory for the 25 UMTRAP sites. At the end of 1989, over 6.5 million cubic meters of mill tailings and other (subordinate) wastes had been stabilized at eight sites where site reprocessing activities were completed.[8] In addition, 2.2 million cubic meters of similar waste had been stabilized at two sites where reprocessing activities are still under way. The subordinate wastes include soils contaminated by windblown tailings, ore in storage areas, material underlying tailings piles, and contaminated soils from vicinity properties. At the Edgemont, South Dakota, site, there are approximately 100 vicinity properties containing 4000 cubic meters of subordinate wastes. It should be noted that quantities of subordinate wastes typically increase as remedial action 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 radioactivity level 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 6.2, UMTRAP activities are scheduled to be completed by September 1994.

Projected characteristics of wastes from uncompleted UMTRAP sites are given in Table 6.3. The values for actinide radioactivity given in this table are calculated based on the assumption that the ore is 3.2 billion years old and that all of the daughter products from the uranium present in the ore are also present in the tailings. The radioactivity reported for ^{226}Ra is determined from representative samples, while that reported for ^{222}Rn is an averaged (transpiration) value estimated from a number of measurements taken over the surface of a tailings pile.

During 1989, UMTRAP achieved the following major accomplishments:

- Completed remedial actions at the Green River, Utah, site and at the Converse County and Riverton, Wyoming, processing sites.
- Completed 69% of the remedial actions at Tuba City, Arizona; 65% at Durango, Colorado; Phase I at Ambrosia Lake, New Mexico, Grand Junction, Colorado, and New and Old Rifle, Colorado; and 38% in Monument Valley/Mexican Hat, Utah.
- Initiated contracts covering remedial actions on 737 vicinity properties at 8 designated sites.

6.2.3 Formerly Utilized Sites Remedial Action Program

The Formerly Utilized Sites Remedial Action Program (FUSRAP) is primarily concerned with the waste cleanup of sites that were formerly used to support the nuclear activities of DOE's predecessor agencies, the Manhattan Engineer District (MED), established for the Manhattan Project, and the Atomic Energy Commission (AEC). The sites of concern were mostly privately and institutionally owned and were used primarily for research,

processing, and storage of uranium and thorium ores, concentrates, and residues.[10,11] When these sites were no longer required to support the nuclear activities of MED and AEC, they were decommissioned in accordance with the health and safety guidelines that were applicable at that time. Those guidelines do not necessarily meet today's more stringent radiological criteria for restricted and unrestricted use. In 1974, AEC initiated a survey program whose aim was to identify formerly utilized MED/AEC sites and characterize their radiological conditions. As a result, in 1977, DOE formalized FUSRAP, and a generic plan was drafted with the following objectives:[12]

- Effect appropriate remedial action and/or controls, as required, consistent with authorization and appropriation by Congress;
- Develop acceptable storage/disposal sites in consultation with the affected states; and
- Certify the acceptability of the sites for future use.

Initially, formerly utilized MED/AEC sites were identified and selected as candidates for remedial action through a historical records search. Later, other sites (not necessarily formerly utilized in support of MED/AEC) were designated by Congress for remedial action under FUSRAP. Thirty sites have been identified as candidates for remedial action, and one additional site has been identified as requiring continued radiological surveillance to monitor the efficacy of the remedial action performed.[13] Those sites authorized to receive remedial action and the health priority rating for each site are given in Table 6.4. Approximately one-half of these sites are in the northeastern part of the country, as can be seen in Fig. 6.5.

Initial remedial action activities have been completed at 10 of the 30 sites and partially completed at 8 additional sites, as shown in Table 6.5. Table 6.6 gives the estimated volumes of waste from FUSRAP activities remaining to be completed. Only waste having low radioactivity is anticipated from cleanup activities. Although very small amounts of some transuranic nuclides may be present, no TRU waste is expected from FUSRAP activities. Most waste material will be contaminated soil and building rubble, and the total volume of LLW is estimated to be about 1,451,700 m^3, including waste that has already been placed in storage. Site radiological surveys have developed considerable detailed information, and comprehensive site-by-site data are given in a number of reports listed in ref. 14.

6.3 DECONTAMINATION AND DECOMMISSIONING

Decontamination and decommissioning (D&D) environmental restoration activities are divided into two portions, the D&D Program, whose objective.. is to decontaminate and decommission inactive, surplus DOE facilities formerly associated with the government's defense efforts; and the SFMP, whose objective is to decontaminate and decommission inactive, surplus DOE facilities formerly associated with civilian projects.

6.3.1 D&D Program

The D&D Program is primarily concerned with the safe caretaking of surplus government nuclear facilities until either their decontamination for reuse or their complete removal. It includes approximately 220 radioactively contaminated, DOE-owned facilities. These facilities are concentrated in seven locations throughout the United States. D&D facilities include such installations as production reactors, fuel reprocessing plants, laboratories, storage tanks, stacks, pipelines, waste treatment systems, solid waste disposal facilities, ponds, cribs, ditches, and areas contaminated by uranium and thorium from mill tailings. The objectives of the D&D Program are to decontaminate these facilities and to eliminate any potential hazards to public health and the environment. The scheduled period of environmental restoration activity for the major D&D Program sites is given in Table 6.7 (data from ref. 15).

The predominant wastes to be generated by cleanup of D&D facilities are LLW and mill tailings. Some TRU wastes are also involved. The projected waste volumes of these wastes are summarized in Table 6.7 for project sites in the affected states. Initial characterization of the sites has identified the waste volumes that may be soil, building rubble, metal, and miscellaneous materials. Site surveys are in progress to better define the physical, chemical, and isotopic nature of these wastes. Almost 44% of the LLW is projected to come from the Grand Junction Site in Colorado, and about 28% is estimated to come from the Mound Plant in Ohio. Smaller amounts of LLW are projected for the other five states. Over 60% of the projected TRU waste is expected to result from decontaminating designated facilities at the Hanford Site in Washington. The D&D Program is responsible for environmental restoration of uranium mill tailings and contaminated soils at the Grand Junction Projects Office Site in Colorado. This material accounts for over 43% of the projected volume of all wastes from D&D Program activities.

The waste volume projections of Table 6.7 are conservative in that they assume all wastes from decommissioning operations will be contaminated and require disposal at a radioactive disposal site. Factors that will modify these waste volume projections are selection of cleanup criteria, completion of more detailed radiological characterizations of the D&D facilities, and selection of a disposition mode for each facility. Waste volume reduction and decontamination techniques (e.g., segmentation, smelting, electropolishing, and vibratory finishing) will be employed, as practicable, and will further affect volume estimates and categorization.

6.3.2 Surplus Facilities Management Program

The objectives of the Surplus Facilities Management Program (SFMP) are to decontaminate about 30 radioactively contaminated, DOE-owned facilities that have been declared surplus to government needs and to eliminate any potential hazards to public health and the environment.[16] These facilities, which have been categorized and are administered as civilian projects, are located throughout 12 states. The SFMP facilities include such installations as power and research reactors, fuel reprocessing plants, laboratories, storage tanks, stacks, pipelines, waste treatment systems, solid waste disposal facilities, ponds, cribs, ditches, and areas contaminated by uranium and thorium from mill tailings. The SFMP was formally established in 1978, and the projected schedules for its current projects are given in Table 6.8 (data from refs. 15 and 16).

The predominant wastes in SFMP sites are LLW and mill tailings, with some TRU wastes also involved. The projected volumes[15] of these wastes are summarized in Table 6.8 for each of the affected states. Initial characterization of many of the sites has identified the waste volumes that may be soil, building rubble, metal, and miscellaneous materials. Site surveys are in progress to better define the physical, chemical, and isotopic nature of these wastes. Almost four-fifths of the LLW, excluding mill tailings, is projected to come from the Weldon Spring Site in Missouri, and about one-sixth is estimated to come from the Niagara Falls Storage Site in New York. Smaller amounts of LLW are projected for the other ten states. Most of the projected TRU waste is expected to result from decontaminating designated facilities at the Battelle Columbus Laboratory in Ohio. The SFMP's responsibilities for environmental restoration on mill tailings are for the Monticello, Utah, site. These wastes account for nearly two-thirds of the projected volume of all wastes from SFMP activities.

The waste volume estimates of Table 6.8 are conservative in that they assume that all wastes from SFMP operations will be contaminated and require disposal at a radioactive waste disposal site. Factors that will modify these waste volume projections are the selection of release criteria, the completion of more detailed radiological characterizations of the SFMP facilities, and the selection of a disposition mode for each facility. Waste volume reduction and decontamination techniques (e.g., segmentation, smelting, electropolishing, and vibratory finishing) will be employed, as practicable, and will further affect volume estimates and categorization.

6.4 REFERENCES

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3. 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.

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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).

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8. Mark L. Matthews, U.S. Department of Energy, Uranium Mill Tailings Project Office, Albuquerque, New Mexico, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, transmitting updated summary of wastes from Uranium Mill Tailings Remedial Action Program activities, dated Mar. 8, 1990.

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).

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11. W. R. Voight, DOE Headquarters, memo to J. W. LaGrone, DOE/Oak Ridge Operations Office, concerning designation of sites for remedial action, dated Dec. 17, 1985.

12. U.S. Department of Energy, A Background Report for the Formerly Utilized Manhattan Engineer District/Atomic Energy Commission Sites Program, DOE/EV-0097, Washington, D.C. (September 1980).

13. William M. Seay, U.S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, Tennessee, letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update to Data for Inclusion in Integrated Data Base for 1990," dated Apr. 13, 1990.

14. U.S. Department of Energy, Integrated Data Base for 1986: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006, Rev. 2, Table 6.3, p. 187, Oak Ridge National Laboratory, Oak Ridge, Tennessee (September 1986).

15. James W. Fiore, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, Washington, D.C., letter to R. L. Pearson, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Update of Decontamination and Decommissioning (D&D) Data in the Integrated Data Base for 1990: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," dated Apr. 12, 1990.

16. U.S. Department of Energy, Program Plan FY 1989: Surplus Facilities Management Program, DOE/NE-0096, Washington, D.C. (November 1988).

Table 6.1. Summary of waste volumes from environmental restoration activities

Program	Waste volume, 10^3 m^3			
	TRU	LLW	Mill tailings	Other[a]
A. Permanent storage[b,c]				
UMTRAP			9,765.2	
FUSRAP		20.4		
GJRAP			52.07[d]	
Total		20.4	9,817.27	
B. Interim storage[b,c]				
FUSRAP		170.2		
C. Estimated remaining inventory[e]				
UMTRAP			16,485.8[f]	5,791.1
FUSRAP		1,261.1		
D&D	0.6	110.0	84.1	
SFMP	2.4	968.4	1,529.0	
Total	3.0	2,339.5	18,098.9	5,791.1

[a]"Other" includes all contaminated material outside the immediate tailings pile. Once the cover is placed, all permanently stored material is considered to be tailings.

[b]As of December 31, 1989.

[c]Past inventories of wastes from D&D Program and SFMP activities are included in the inventories reported for DOE activities in Chapters 3 and 4.

[d]GJRAP completed in 1988.

[e]See Tables 6.3, 6.6, 6.7, and 6.8 for estimated project completion dates.

[f]About 4.2% (696,150 m^3) of this amount is a mixture of mill tailings and other waste.

Table 6.2. UMTRAP site descriptions, status, scheduled duration, and volume of permanently stored mill tailings[a]

State and site (last operation)	Site area (ha)	Remedial action status and scheduled duration as of Dec. 31, 1989	Permanently stored mill tailings[b] (m^3)
		High-priority sites	
Colorado			
Durango (March 1963)	51	In progress (65% complete)[c]	1,912,500
Grand Junction (March 1970)	23.9;[d] 26.3[e]		
Phase I[f]		Completed	
Phase II[g]		In progress (1% complete)	
Gunnison (April 1962)	14.2;[d] 15[e]	Planned; May 1991/28 months	
New Rifle (December 1972)	12.9;[d] 29.9[e]		
Phase I[f]		Completed	
Phase II[g]		Pending; October 1990/38 months	
Old Rifle (1958)	5.5;[d] 18.8[e]		
Phase I[f]		Completed	
Phase II[g]		Pending; October 1990/38 months	
New Mexico			
Shiprock (August 1968)	29.1[d]	Completed in 1986	2,142,000
Pennsylvania			
Canonsburg (1957)	11.6[d]	Completed in 1985	130,050
Utah			
Salt Lake City (Feb. 1964/July 1968)	24.3[d]	Completed in 1987	2,073,150
Wyoming			
Riverton (mid-year 1963)	29.1;[d] 56.7[e]	Completed in 1989	1,224,000
		Medium-priority sites	
Arizona			
Tuba City (Sept. 1966)	8.9;[d] 128.3[e]	In progress (69% complete)[c]	1,246,950
Colorado			
Naturita (1963)	h; 20.2[e]	Planned; April 1992/17 months	
New Mexico			
Ambrosia Lake (Apr. 1963)	44.9;[d] 230.7[e]		
Phase I[f]		Completed	
Phase II[g]		Pending; April 1991/29 months	
Oregon			
Lakeview (1961)	16.2[d]	Completed in 1987	719,100
Texas			
Falls City (Aug. 1973)	59.1;[d] 123.4[e]	Planned; July 1991/36 months	
Utah			
Green River (Jan. 1961)	3.6;[d] 16.3[e]	Completed in 1989	160,650
Mexican Hat (1965)	28.3;[d] 73.4[e]	In progress (38% complete)	
		Low-priority sites	
Arizona			
Monument Valley (1968)	11.0;[d] 11.5[e]	In progress (38% complete)	
Colorado			
Maybell (Nov. 1964)	29.7;[d] 69.2[e]	Planned; April 1992/18 months	
Slick Rock – NC site (1957)	2.4;[d] 7.6[e]	Planned; April 1992/17 months	
Slick Rock – UC site (Dec. 1961)	7.7;[d] 26.3[e]	Planned; April 1992/17 months	
Idaho			
Lowman (1960)	5.0;[d] 7.0[e]	Planned; April 1992/6 months	

Table 6.2 (continued)

State and site (last operation)	Site area (ha)	Remedial action status and scheduled duration as of Dec. 31, 1989	Permanently stored mill tailings[b] (m^3)
	Low-priority sites (continued)		
North Dakota			
Belfield (Oct. 1965)[i]	h; 14[e]	Planned; April 1992/6 months	
Bowman (Feb. 1967)[i]	h; 26[e]	Planned; April 1992/6 months	
South Dakota			
Edgemont[j]	NA[k]	Completed in 1988	34,400[l]
Wyoming			
Converse County (June 1965)	2.0;[d] 6.3[e]	Completed in 1989	122,400
Total			9,765,200

[a]Data from ref. 8.
[b]Tailings and other wastes combined with radon barrier in place. Other components of the cover and site drainage features may not be completed.
[c]Tailings have been stabilized.
[d]Tailings site area.
[e]Other wastes site area.
[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]No tailings; uraniferous lignite ashing plant; ore roasted and shipped away.
[j]Vicinity properties only.
[k]Not applicable.
[l]Buried in a permanently capped cell repository a few miles south of Edgemont.

Table 6.3. Projected waste characteristics at uncompleted UMTRAP sites as of December 31, 1989[a]

State and site	Estimated waste volume, m^3		Radioactivity			
			Mill tailings		Other waste	
	Mill tailings	Other waste	^{226}Ra (pCi/g)	^{222}Rn (pCi/m^2·s)	^{226}Ra (pCi/g)	^{222}Rn (pCi/m^2·s)
Arizona						
Monument Valley	826,200	76,500	49-49	37-48	89	9-70
Colorado						
Grand Junction	2,172,600	1,017,450	665	550	b	b
Gunnison[c]	374,850	206,550	314	150	c	c
Maybell	2,210,850	214,200	187	125	b	b
Naturita	d	474,300	d	d	46	0.5-124
New Rifle	2,103,750	841,500	800	70-1,400	b	b
Old Rifle	252,450	229,500	700	210-1,300	b	b
Slick Rock; NC site[c]	30,600	42,075	267	240	c	c
Slick Rock; UC site[c]	290,700	141,525	143	70	c	c
Subtotal	8,262,000	3,167,100				
Idaho						
Lowman	45,900	99,450	133	50-150	b	b
New Mexico						
Ambrosia Lake	2,034,900	1,438,200	455	120	b	b
North Dakota						
Belfield	e	53,550	e	e	61	16
Bowman	e	68,850	e	e	32	15
Subtotal		122,400				
Texas						
Falls City	3,526,650	734,400	200	3-78	b	b
Utah						
Mexican Hat	1,790,100	153,000	624-763	16-1,600	b	b
Total	16,485,750	5,791,050				

[a]Data from ref. 8.
[b]Data not provided.
[c]Tailings/other wastes combined.
[d]Moved from site in 1977-1979; only contaminated soil remains; mill area susceptible to flooding.
[e]No tailings, uraniferous lignite ashing plant; ore roasted and shipped away.

Table 6.4. Authorization and health priority rating for FUSRAP sites[a]
(Listing as of December 1989)

Project No.	Name of site	Health priority[b]
	Authorized to receive remedial action under Atomic Energy Act of 1954, as amended	
101	Acid/Pueblo Canyon; Los Alamos, NM[c]	NA
102	Albany Metallurgical Center; Albany, OR[d]	L
103	Ashland Oil Co. #1; Tonawanda, NY	M
104	Bayo Canyon; Los Alamos, NM[c]	NA
105	Chupadera Mesa, White Sands Missile Range, NM[e]	NA
108	Du Pont and Company; Deepwater, NJ	L
110	W. R. Grace & Company; Curtis Bay, MD	L
114	Kellex/Pierpont; Jersey City, NJ[c]	NA
115	Niagara Falls Storage Site (Vicinity Properties); Lewiston, NY[c]	NA
116	St. Louis Downtown Site; St. Louis, MO	L/M
117	Middlesex Landfill; Middlesex, NJ[c]	NA
118	Middlesex Sampling Plant; Middlesex, NJ[f,g]	L
119	National Guard Armory; Chicago, IL[c]	L
123	Seaway Industrial Park; Tonawanda, NY	L/M
125	Shpack Landfill; Norton, MA	L
126	Aliquippa Forge; Aliquippa, PA[d]	L
127	Ventron; Beverly, MA[d]	M
129	Linde Air Products; Tonawanda, NY	L
130	University of California; Berkeley, CA[c]	NA
131	University of Chicago; Chicago, IL[c]	NA
132	Ashland Oil Co. #2; Tonawanda, NY	TBD
134	St. Louis Airport (Vicinity Properties); St. Louis, MO	L
141	General Motors; Adrian, MI	L
142	Seymour Specialty Wire; Seymour, CT	L
143	Elza Gate; Oak Ridge, TN	M
	Authorized to receive decontamination research and development action under FY 1984 Energy and Water Development Appropriations Act, as amended	
137	Wayne/Pequannock, NJ[d,g]	L
138	Maywood, NJ[d,g]	H
139	Colonie, NY[d,g]	L
140	Latty Avenue Properties; Hazelwood, MO[d]	M
	Authorized to receive remedial action under FY 1985 Energy & Water Development Appropriations Act	
153	St. Louis Airport Site; St. Louis, MO	L
	Authorized to receive radiological surveillance only under Atomic Energy Act of 1954, as amended	
121	Palos Park Forest Preserve; Cook County, IL	TBD

[a]Data from ref. 13.
[b]NA – not applicable; L – low; M – medium; L/M – low to medium; H – high; and TBD – to be determined.
[c]All remedial actions required under FUSRAP have been completed.
[d]Remedial action is in progress.
[e]Remedial action is not required.
[f]Remedial action completed on 5 vicinity properties in December 1980 and on the remaining 28 vicinity properties in January 1982 in Phases I and II of this project. Phase III remedial action (cleanup of the DOE storage site) is suspended pending selection and development of a disposal site.
[g]DOE-owned property.

Table 6.5. 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, 1989	Permanently stored waste, m^3		Interim stored waste (m^3)
			LLW	Stabilized	
California					
Gilman Hall, Univ. of California, Berkeley	b	Completed in FY 1982	23		
Connecticut					
Seymour Specialty Wire	b	Planned in FY 1994			
Illinois					
Palos Park Forest Preserve, Cook County	7.7	Radiological surveillance only[c]		15,800	
Laboratories at Univ. of Chicago, Chicago	b	Completed in FY 1987	32		
National Guard Armory, Chicago	b	Completed in 1987	15		
Maryland					
W. R. Grace and Company, Curtis Bay	1.6	Planned in FY 2000-2001			
Massachusetts					
Shpack Landfill, Norton	3.2	Planned in FY 1992			
Ventron, Beverly	1.2	Partially completed; to be completed in FY 1990-1991	176		
Missouri					
St. Louis Airport, St. Louis	8.8	Planned in FY 1992			
St. Louis Airport (Vicinity Properties), St. Louis	b	Planned in FY 1995-1996			
Latty Avenue Properties, Hazelwood	b	Partially completed; to be continued through 1997			24,200[d]
St. Louis Downtown Site, St. Louis	18.2	Planned in FY 1998-1999			
Michigan					
General Motors, Adrian	b	Planned in FY 1994			
New Jersey					
E. I. du Pont de Nemours and Co., Deepwater	283	Planned in FY 2001			
Kellex Research Facility, Jersey City	6.2	Completed in FY 1981	209		
Middlesex Municipal Landfill, Middlesex	1.2	Completed in 1986			23,900[e]
Middlesex Sampling Plant, Middlesex	3.9	Partially completed; to be completed in FY 1994-1996			26,900[f]
W. R. Grace/Sheffield Brook/other properties, Wayne and Pequannock	b	Partially completed; to be continued through FY 2000			29,400[g]
Stepan Chemical Co., Ballod property and private properties on Latham St. and Davidson Ave., Maywood	b	Partially completed; to be continued through FY 2001			26,700[h]
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	
Chupadera Mesa, White Sands Missile Range	b	None required[i]			

Table 6.5 (continued)

State and site	Site area (ha)	Remedial action status and schedule as of Dec. 31, 1989	Permanently stored waste, m^3		Interim stored waste (m^3)
			LLW	Stabilized	
New York					
Linde Air Products Div., Tonawanda	22.2	Planned in FY 1993-1994			
Colonie Interim Storage Site, Colonie	b	Partially completed; to be continued through FY 1997			918[j]
Niagara Falls Storage Site (Vicinity Properties), Lewiston	b	Completed in FY 1986			38,200[k]
Ashland Oil Co. (No. 1), Tonawanda	3	Planned in FY 1995			
Ashland Oil Co. (No. 2), Tonawanda	1	Planned in FY 1993			
Seaway Industrial Park, Tonawanda	4.8[l]	None planned/required			
Oregon					
Albany Metallurgical Research Center, Albany	b	Partially completed; to be completed in FY 1993	2,650		
Pennsylvania					
Aliquippa Forge, Aliquippa	0.34[m]	Partially completed; to be be completed in FY 1994			
Tennessee					
Elza Gate, Oak Ridge	8.9	Planned in FY 1992			
Total (all sites)			3,403	16,960	170,218

[a]Data from ref. 13.
[b]Not determined.
[c]Authorized for radiological surveillance only. Estimated 15,800 m^3 of stabilized waste entombed on-site being monitored.
[d]24,200 m^3 of waste in interim storage on-site.
[e]23,900 m^3 of waste transferred to Middlesex Sampling Plant for interim storage.
[f]26,900 m^3 of waste in interim storage on-site. Does not include 23,900 m^3 of Middlesex Municipal Landfill waste which is stored on-site.
[g]29,400 m^3 of off-site property waste transferred to interim storage on-site.
[h]26,700 m^3 of waste in interim storage on-site.
[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]Existing waste in the Seaway Landfill will remain in place based on pathway analysis findings.
[m]Total floor area that was surveyed; only isolated patches of radioactive contamination were found.

Table 6.6. Projected waste characteristics at uncompleted FUSRAP sites[a]

State and site	Estimated waste volume (m^3)	Principal constituents	Identified 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	306	Soil, concrete, metal, and rubble	^{238}U, ^{235}U, ^{226}Ra, ^{210}Pb
Ventron, Beverly	3,650	Soil, concrete, rubble, metal, and building material	^{238}U
Subtotal	3,956		
Missouri			
St. Louis Airport	177,000	Soil	^{238}U, ^{230}Th, ^{226}Ra
St. Louis Airport (Vicinity Properties), St. Louis	148,000	Soil	^{238}U, ^{226}Ra
Latty Avenue Properties, Hazelwood	102,000	Soil, rubble	^{238}U, ^{231}Pa, ^{230}Th, ^{227}Ac, ^{226}Ra
St. Louis Downtown Site, St. Louis	220,000	Soil, building material, and rubble	^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{222}Rn
Subtotal	647,000		
Michigan			
General Motors, Adrian	153	Soil, building material, and metal	^{238}U
New Jersey			
E. I. du Pont de Nemours and Co., Deepwater	5,850	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	288,000	Soil, rubble	^{235}U, ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K
Subtotal	364,550		
New York			
Linde Air Products Div., Tonawanda	16,500	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	19,400	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
Subtotal	204,400		

Table 6.6 (continued)

State and site	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
Oregon			
Albany Metallurgical Research Center, Albany	306	Soil, building material, and plumbing	^{238}U, ^{232}Th
Pennsylvania			
Aliquippa Forge, Aliquippa	29	Soil, concrete, metal	^{238}U, alpha, beta-gamma
Tennessee			
Elza Gate, Oak Ridge	13,200	Soil, concrete, building material, and plumbing	^{238}U, ^{226}Ra
Total (all sites)	1,261,113		

[a]Data from ref. 13.

Table 6.7. Projected remaining volumes (m^3) of low-level and transuranic wastes, status, and schedule for completion of D&D Program projects as of December 31, 1989[a]

Location and project	Soil		Rubble		Metal		Miscellaneous		Total		Disposal site	Environmental restoration status	Scheduled year of completion
	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU			
Colorado													
Grand Junction Site	84,100[b]	0	796	0	344	0	0	0	85,240	0	c	Under way	1992
Idaho													
Idaho National Engineering Laboratory	568	0	8,939	0	3,988	0	259	1	13,754	1	INEL	Under way	2000
Nevada													
Nevada Test Site	0	0	900	0	100	0	0	0	1,000	0	NTS	Planned[d]	2000
New Jersey													
New Brunswick Laboratory	3,200	0	200	0	60	0	60	0	3,520	0	NTS	Planned[e]	1992
New York													
Knolls Atomic Power Laboratory	0	0	2,500	0	2,924	0	2,500	0	7,924	0	TBD	Planned[f]	2001
Ohio													
Mound Plant	35,424	31	7,967	6	7,034	111	4,456	10	54,967	158	NTS	Under way	2002
Tennessee													
Oak Ridge National Laboratory	17,035	0	2,805	0	775	35	572	25	21,187	60	ORNL	Under way	2005
Washington													
Hanford Site[g]	105	15	769	96	2,891	114	2,798	111	6,554	336	HANF	Under way	2012
Total									194,146	555			

[a]Data from ref. 15.
[b]Uranium mill tailings and contaminated soil.
[c]UMTRAP disposal site at Cheney Reservoir.
[d]Environmental restoration to begin in 1994.
[e]Environmental restoration to begin in 1991.
[f]Environmental restoration to begin in 1992.
[g]Does not include disposition of 100 area reactor blocks; EIS is to determine D&D mode.

Table 6.8. Projected remaining volumes (m^3) of low-level and transuranic wastes, status, and schedule for completion of SFMP projects[a]

Location and project	Soil		Rubble		Metal		Miscellaneous		Total		Disposal site	Environmental restoration status	Scheduled year of completion
	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU	LLW	TRU			
California													
Santa Susana Field Laboratory	1,355	0	1,621	0	581	0	495	0	4,052	0	HANF/NTS	Under way	1998
UC-Davis Waste Retention System	3,068	0	70	0	50	0	100	0	3,288	0	HANF	Under way	1993
Idaho													
Idaho National Engineering Laboratory	2	0	768	0	295	0	15	0	1,080	0	INEL	Under way	1992
Illinois													
Argonne National Laboratory	0	0	240	0	439	0	0	0	679	0	INEL	Under way	1995
Missouri													
Weldon Spring Site	260,000	0	110,000	0	8,000	0	340,000	0	718,000	0	b	Under way	1999
New Mexico													
Los Alamos National Laboratory	0	0	350	0	130	11	125	0	605	11	LANL	Under way	1991
New York													
Lewiston (Niagara Falls Storage Site)	118,107	0	8,793	0	0	0	30,783	0	157,683	0	b	Under way	1999
Ohio													
Mound Plant	595	113	255	23	113	8	142	0	1,105	144	NTS	Under way	1993
Battelle Columbus Laboratory	945	85	1,849	1,014	616	507	308	84	3,718	1,690	HANF	Planned[c]	1993
South Carolina													
Savannah River Site	0	0	0	0	0	0	45	3	45	3	SRS	Planned[d]	1997
Tennessee													
Oak Ridge National Laboratory	20	0	80	0	606	125	375	0	1,081	125	ORNL	Planned[d]	2000
Utah													
Monticello Site	1,606,000[e]	0	0	0	0	0	0	0	1,606,000	0	b	Under way	1995
Washington													
Hanford Site	0	0	0	0	4	226	14	226	18	452	HANF	Under way	2004
SFMP total									2,497,354	2,425			

[a]Data from refs. 15 and 16.
[b]Off-site radioactive waste disposal is not planned.
[c]Environmental restoration to begin in 1990.
[d]Environmental restoration to begin in 1992.
[e]Uranium mill tailings comprise 1,529,000 m^3 of this volume.

ORNL-PHOTO 6200-90

(*a*)

(*b*)

Photo 7.1. The Deep Kerf Cutter in use at the West Valley Demonstration Project: (a) technicians operating the cutter, which uses an ultrahigh pressure stream of water and abrasive to cut steel-reinforced concrete walls 3 to 5 ft thick; (b) removal of concrete wall sections produced by the cutter. (Courtesy of the West Valley Demonstration Project, West Valley, New York.)

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 data shown in Table 7.2 are based on refs. 3–9 and assume a 4-year period for decommissioning, beginning 2 years after reactor shutdown to allow sufficient preparation time for D&D operations. For these projections, it was further assumed that 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 reactors are upgraded to extend their operating lifetimes or if significant radioactivity decay time is allowed before decommissioning operations begin.

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). 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.) On a relative basis, it is estimated that the volume of decommissioning wastes from conversion, enrichment, and fuel fabrication facilities is less than 2% of the waste volume from decommissioning a PWR (Table 7.3, col. 6). Table 7.3 also shows that, for conversion and fabrication facilities, the volume of wastes from decommissioning will be significantly less than the volume of wastes produced from normal lifetime operations. Not shown in this table are the additional wastes that will result from decommissioning of research, training, and test reactors.[13,14] However, the total volumes of these wastes are not 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:[5,8] (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). Contaminated materials include much of the piping and equipment in the reactor containment 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 decontamination. 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. Recent studies have been made to better define the characteristics of GTCC wastes (see, for example, ref. 19). Some of these 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,[20-21] 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.[5,8] 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.

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, ^{58}Co and ^{60}Co control the radiation levels; from 4 to 100 years, ^{60}Co controls radiation levels; and after 100 years, ^{59}Ni and ^{94}Nb control radiation levels.[8] 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. Table 7.7 shows the effects of various decommissioning alternatives on the volumes and radioactivities of D&D wastes from a reference BWR[4-6] and a reference PWR.[7-9] 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 decommissioning activities at the Shippingport Station Decommissioning Project. This is the site of the first domestic commercial power reactor and is currently part of the civilian SFMP. 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 is 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 1990. By the end of 1989, 145.3 t of core debris had been shipped to INEL for R&D testing and storage.[29]

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

The Commonwealth Edison Company has issued a preliminary 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 59-MW(e) Pathfinder BWR was placed in the SAFSTOR mode following its shutdown in 1967. Work on dismantling the reactor is expected to begin in 1990. Waste inventories and projections from D&D activities at this reactor site will be documented in future IDB Program reports.

The 40-MW(e) Peach Bottom HTGR 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.[33]

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. 34).

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 a decommissioning study[35] made of the 65-MW(e) Humboldt Bay Unit 3 BWR and the 1100-MW(e) Diablo Canyon PWR Units 1 and 2. Projections for the Humboldt Bay BWR in Table 7.14 include wastes from completely dismantling the reactor following a SAFSTOR period of about 30 years. 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 ref. 37). This reactor was shut down in August 1989.

Inventories and projections of wastes from decommissioning activities at the Cimarron (Oklahoma) Fuel Fabrication Facility are provided in Table 7.18 (data from ref. 38). Decontamination work at this fabrication plant is scheduled to be completed during 1990.

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. Over the next 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.[39] As of the end of 1989, 30 submarines had been taken out of active service. In eight of these submarines, the reactor compartment was first defueled, then later removed and disposed of at a government burial site. The remaining 22 submarines with reactor compartments were being held in protective storage.[2]

7.4 REFERENCES

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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)
Prior to 1976	4	103	2	20	6	123
1976	1	65			1	65
1978	1	200			1	200
1979			1	926[c]	1	926
1980			1	265	1	265
1982			1	72	1	72
1987	1	48			1	48
1989			1	918	1	918
Totals through 1989	7	416	6	2,201	13	2,617
1995	1	620			1	620
2000			1	175	1	175
2002	1	72			1	72
2007			2	1,018	2	1,018
2009	2	1,444	1	490	3	1,934
2010	2	1,205	2	1,197	4	2,402
2011	2	1,583	3	2,175	5	3,758
2012	3	1,958	3	2,306	6	4,264
2013	2	2,130	9	6,976	11	9,106
2014	7	5,865	6	4,960	13	10,825
2015			3	2,965	3	2,965
2016	2	1,886	5	4,532	7	6,418
2017			4	3,660	4	3,660
2018	1	784	1	912	2	1,696
2020			4	3,999	4	3,999
Projected totals (1990–2020)	23	17,547	44	35,365	67	52,912

[a]Data from refs. 1 and 2.

[b]Projected reactor shutdown dates are based on 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 accident. Upon completion of the present cleanup campaign, the plant will be placed in a monitored storage mode for an indefinite period.

Table 7.2. Projections of cumulative volume, radioactivity, and thermal power of wastes from decommissioning commercial light-water reactors shut down during 1990-2020[a,b,c]

Waste type	Volume (m^3)	Activity (Ci)	Thermal power (W)
Boiling-water reactors			
Class-A LLW	281,314	29,671	241
Class-B LLW	5,666	92,257	758
Class-C LLW	805	300,425	1,236
Subtotals	287,785	422,353	2,235
Greater-than-Class-C LLW[d]	723	7,867,256	32,780
Totals for D&D of BWRs	288,508	8,289,609	35,015
Pressurized-water reactors			
Class-A LLW	540,567	153,027	816
Class-B LLW	6,440	215,534	1,900
Class-C LLW	512	172,842	1,391
Subtotals	547,519	541,403	4,107
Greater-than-Class-C LLW[e]	4,004	23,924,413	187,714
Totals for D&D of PWRs	551,523	24,465,816	191,821
Total light-water reactors			
Total LLW	835,304	963,756	6,342
Greater-than-Class-C LLW	4,727	31,791,669	220,494
Totals for D&D of LWRs	840,031	32,755,425	226,836

[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 2026, the last year in which wastes are collected from reactors shut down in year 2020.

[d]Contribution from the core shroud (see refs. 4 and 5).

[e]Contributions from the lower core barrel, thermal shields, lower grid plate, and core shroud (see refs. 7 and 8).

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

Fuel cycle facility	Typical capacity	Number of equivalent 1-GW(e) PWRs annually supported by typical facility[b]	40-year waste generation[c] (m^3)	Decommissioning wastes[d] (m^3)	Relative decommissioning waste volumes[e]
Uranium conversion plant (solvent extraction process)	10,000 MTIHM/year	50	23,800[f]	1,260[f]	0.0016
Uranium enrichment plant (gaseous diffusion process)	8,750,000 kg SWU/year	73	8,000[f]	12,740[f]	0.0112
Fuel fabrication plant	1,000 MTIHM/year	40	98,800[f]	1,090[f]	0.0017
Boiling-water reactor	1 GW(e)	1	15,460[f] 640[g]	16,400[f] 41[g]	1.0540
Pressurized-water reactor	1 GW(e)	1	6,200[f] 150[g]	15,480[f] 113[g]	1.0000

[a]Based on information reported in refs. 3–12. A 40-year operating lifetime is assumed for all facilities.
[b]Assuming a 75% reactor capacity factor and the fuel cycle requirements of Table A.1 in Appendix A.
[c]Packaged LLW volumes generated during a 40-year operating lifetime.
[d]Assumes decommissioning immediately after shutdown.
[e]These relative values are calculated by $\frac{[(\text{total decommissioning waste volume})/(\text{number of PWRs supported})]}{[\text{total decommissioning waste volume of 1-GW(e) PWR}]}$.
[f]Class-A, Class-B, and Class-C LLW.
[g]Greater-than-Class-C LLW.

Table 7.4. List of U.S. civilian reactors shut down or dismantled as of December 31, 1989[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
Elk River Power Station	Elk River, MN	Boiling-water	22	58	1968	DECON	DECON completed[b]
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[c]	17	1967	SAFSTOR	SAFSTOR
Fort St. Vrain Reactor	Platteville, CO	High-temperature, gas-cooled	330	842	1989	TBD[d]	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
Indian Point Station, Unit 1	Buchanan, NY	Pressurized-water	265	615	1974	TBD[e]	TBD
La Crosse Nuclear Generating Station	Genoa, WI	Boiling-water	48	165	1987	SAFSTOR	SAFSTOR
Pathfinder Atomic Plant	Sioux Falls, SD	Boiling-water	59	190	1967	SAFSTOR	SAFSTOR
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[f]
Saxton Nuclear Experimental Reactor Project	Saxton, PA	Pressurized-water	3	24	1972	SAFSTOR	DECON in progress[g]
Shippingport Power Station	Shippingport, PA	Pressurized-water	72	236	1982	DECON	DECON completed[h]
Sodium Reactor Experiment	Santa Susana, CA	Sodium-cooled, graphite-moderated	10	30	1964	DECON	DECON completed[i]
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	j	j
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

[a]Based on refs. 2 and 17.
[b]Decommissioning wastes are reported in Table 7.5.
[c]NE = no electricity generated by reactor before it was shut down.
[d]TBD = to be determined. Decommissioning wastes for the DECON option are reported in Table 7.17.
[e]Indian Point Unit 1 has been placed in a mothballed state (a mode of SAFSTOR). Presently, this reactor's condition is being reviewed for approval by the NRC.
[f]Decommissioning wastes are reported in Table 7.16.
[g]DECON of the Saxton facility started in 1986.
[h]Decommissioning wastes are reported in Table 7.8.
[i]Decommissioning wastes are reported in Table 7.6.
[j]TMI-Unit 2 is presently undergoing defueling and decontamination in selected areas. Upon completion of these activities, the plant will be placed in a monitored storage mode for an indefinite period.

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]

Decommissioning alternative	Totals		Class-A LLW		Class-B LLW		Class-C LLW		Exceeds Class-C LLW limits	
	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)	Volume (m^3)	Activity (10^3 Ci)
Reference boiling-water reactor [1,155 MW(e)]										
Immediate decontamination following shutdown	18,985	6,595.8	18,512	13.9	373	42.8	53	239.1	47[c]	6,300.0
Deferred decontamination after a safe storage period of:										
30 years[d]	18,985	180.4	18,652	1.4	233	1.1	53	6.5	47[c]	171.4
50 years[d]	1,783	141.4	1,450	0.2	247	1.0	39	4.7	47[c]	135.5
100 years[d]	1,673	97.2	1,340	0.1	247	0.6	39	3.3	47[c]	93.2
Entombment[e]	8,078	6,586.6	7,605	4.7	373	42.8	53	239.1	47[c]	6,300.0
Reference pressurized-water reactor [1,175 MW(e)]										
Immediate decontamination following shutdown	18,325	4,906.2	17,961	37.3	214	53.1	17	34.3	133[f]	4,781.5
Deferred decontamination after a safe storage period of:										
30 years[d]	18,328	209.1	18,055	1.5	123	0.6	17	1.5	133[f]	205.5
50 years[d]	1,833	159.4	1,568	0.3	115	0.2	17	1.1	133[f]	157.8
100 years[d]	1,783	106.2	1,533	0.2	100	<0.1	17	0.8	133[f]	105.2
Entombment[e]	3,500	4,908.0	3,136	39.1	214	53.1	17	34.3	133[f]	4,781.5

[a]From refs. 4–9. Activities were calculated from data reported in refs. 4–9. 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]Contribution from the core shroud (see refs. 4 and 5).

[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.

[f]Contributions from the lower core barrel, thermal shields, lower grid plate, and core shroud (see refs. 7 and 8).

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

Type of waste	Total waste removed from Shippingport through December 1989	
	Volume (m^3)	Activity (Ci)
Liquid	2,187	0.64
Solid[c]		
Reactor vessel package	283	16,000
Resins	101	41
Asbestos	1,072	2
Compacted trash	24	1
Metallic waste	1,763	42
Large components	326	142
Miscellaneous	2,425	32
Total solid waste	5,994	16,260

[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]Solid waste volume includes total volume 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, 1989	Projected total wastes upon completion of the project[c]
Spent fuel returned to owner utilities[d]		
Mass, MTIHM	142	142
Number of fuel assemblies	625	625
High-level waste generated from reprocessing operations (1966-1972)[e]		
Volume, m^3 (waste form)	1,877 (liquid, sludge, and zeolite)	210 (glass)
Activity, Ci[f]	27,900,000	24,700,000[g]
Transuranic waste generated from presolidification activities and HLW vitrification		
Volume, m^3	42[h]	300
Activity, Ci[f]	66[h]	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	3,207[i]	
Stored waste activity, Ci[f]	351[j]	
Low-level waste incorporated in cement by radwaste treatment system[k]		
Stored waste volume, m^3	1,959	
Stored waste activity, Ci[f]	217	
Low-level waste from post-solidification 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	10,952	
Activity, Ci[f]	1,193	

[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 1989, 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 1,879 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 1995.

[h]Includes 14 m^3 (and 13.2 Ci) of TRU waste generated during 1989 (from HEPA filters).

[i]Comprised of Class A (83.1%), Class B (13.1%), and Class C (3.8%) LLW.

[j]Comprised of Class A (16.7%), Class B (69.6%), and Class C (13.7%) LLW.

[k]Comprised of Class A and Class C LLW (see Table A.12 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 1989)	
		Packaged volume (m^3)	Shipment activity[c] (Ci)
Spent fuel/core debris[d]	145.3	121.8	6,552,224
Low-level and other wastes[e]			
Dry activated waste (DAW)[f]	-	5,238.3	697.3
Wet and solidified waste[g]	-	268.9	7,377.2
Submerged demineralizer system (SDS)[h]	-	45.2	666,344
EPICOR II system liners[i]			
First generation	-	125.7	77,750
Second generation	-	743.2	3,642.6
Defueling water cleanup system (DWCS)[j]	-	7.04	5,710.7
Off-site deconable scrap	-	138.9	4
Totals	145.3	6,689.04	7,313,749.8

[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.

[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 from reactor site[c,d]	
		Volume (m^3/year)	Activity (Ci/year)
1988	SAFSTOR	4.62	70.3
1989–1993	SAFSTOR	9.7	42
1994–1998	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 about 400 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.

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. 34.

[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 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	67[d]
Reactor vessel internals	27[e]
Other components	17
Removal of major equipment	
Main turbine/generator	353
Main condensers	164
Asbestos removal	307
Disposal of contaminated plant systems	
Turbine system	437
Electrical system	386
High-pressure steam and feedwater systems	333
Condensate system	226
Radwaste collection and treatment systems	298
Other systems	449
Decontamination of site buildings	
Refueling	416
Other	30
Disposal of contaminated solid waste	149
Process liquid waste	105
Total	3,827

[a]Based on the information reported in ref. 35.

[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 1985. The projections in this table and in ref. 35 assume delayed dismantling of the reactor begins in 2015, after the current inventory of spent fuel at the site has been shipped to a federal repository.

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

[d]Includes 48 m^3 of Class C LLW.

[e]Includes 23 m^3 of Class C LLW and 4 m^3 of GTCC waste.

Table 7.15. Projected volumes of radioactive wastes from DECON (prompt removal/dismantling) of Diablo Canyon Power Plant 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	1,912
Reactor vessel	256[d]	256[d]
Reactor vessel internals	300[e]	284[f]
Other components	448	448
Disposal of plant systems		
Electrical (contaminated) system	4,120	3,890
Other systems	2,476	1,991
Decontamination of site buildings		
Fuel handling	96	96
Containment and penetration area	958	958
Other	~1	158[g]
Disposal of contaminated solid waste	2,755	2,816
Process liquid waste	586	554
Total	14,347	13,803

[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 and ENTOMB decommissioning options 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. 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 130 m^3 of Class C LLW.

[e]Includes 144 m^3 of Class C LLW and 156 m^3 of GTCC waste.

[f]Includes 128 m^3 of Class C LLW and 156 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	470
Reactor vessel	212
Reactor vessel internals	187
Primary system components and piping	1,337
Total for reactor vessel and components	1,736
Secondary and radwaste systems	7,032
Contaminated structures	813
Processed liquid waste	315
Dry active waste	175
Grand total	10,541

[a]Based on ref. 36.

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

[a]Based on ref. 37. 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]Kaowool is an insulation material.

Table 7.18. 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 1989[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	LLW (LSA)	1,680.30	3.22	1,000
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)	5,824.57	15.00	1,000
Total waste		6,080.46	25.87	1,000

[a]Based on the information provided in ref. 38.
[b]The LLW inventories are included in the commercial disposal site inventories of Chapter 4.
[c]Decontamination work is scheduled to be completed during 1990. More than 90% of the estimated decontamination requirement has been completed.
[d]LSA = low-specific-activity waste.

Photo 8.1. A pit at the Nevada Test Site where mixed LLW (behind the ground sampling system pipes, shown in the center) is kept on an interim basis. (Courtesy of the Hazardous Waste Remedial Actions Program, Oak Ridge, Tennessee, and Reynolds Electrical and Engineering Company, Inc., Las Vegas, Nevada.)

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 materials. 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 unique features of mixed HLW and TRU wastes because 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 the Resource Conservation and Recovery Act (RCRA), as amended,[2] which is administered by the Environmental Protection Agency (EPA) (unless a state has obtained an authorization status). Thus, the treatment, handling, and disposal of mixed wastes are subject to the regulations of the EPA[3] and NRC (or the authorized and agreement states), as well as those of DOE. Table 8.1 (data from ref. 4) 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. 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 broad spectrum of contaminated materials, such as air purifiers, cleaning solutions and cleanup materials, engine oils and grease, epoxies and resins, gravel, laser dyes, paint residues, photographic materials, soils, asphalt, roofing compounds and wall materials, water treatment chemicals, and decommissioned weapons manufacturing equipment.[5] A data base for mixed wastes from activities at government defense installations is being compiled by the Hazardous Waste Remedial Actions Program (HAZWRAP). This data base is being developed to support the DOE Office of Environmental Restoration and Waste Management.

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 which 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 is currently adopting new toxic characterization leaching procedures. Representative data on the chemical and radionuclide compositions of mixed wastes will be reported as more detailed site information is available. Some general categories of mixed wastes based on their hazardous components, as regulated by the EPA, include the following:

- Ignitable materials (e.g., acetone, toluene, and alcohols): include liquids with a flashpoint of 60°C or less. (The flashpoint is the lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air.)
- Corrosive materials: include acids, bases, and crystalline solids (e.g., sodium hydroxide).
- Extraction procedure (EP) toxic materials: solids and liquids designated by the EPA in Subpart C (Part 261.24) of ref. 3 as being toxic. Common examples are mercury and lead.
- Spent solvents: compounds listed in Subpart D (Part 261.31) of ref. 3.
- Spent solutions or sludges: specified in Subpart D of ref. 3 and include various plating waste sludges.
- Discarded chemicals: indicated in Subpart D (Part 261.33) of ref. 3 and include discarded chemical products (e.g., acetone, phenyl compounds) which are container and spill residues.

- Polychlorinated biphenyls (PCBs): subjected to regulation under the Toxic Substances Control Act (TSCA).[6,7]
- Reactive materials: as described in 40 CFR Part 261.23 (ref. 3), include some cyanides and sulfides and materials reacting violently with water. In the tables of this chapter, reactive materials are included in the inventories and generation rates of other mixed wastes whose major hazardous component is not otherwise categorized (e.g., poisons and carcinogens).

These hazardous waste categories are used to summarize the mixed LLW reported for DOE sites in this chapter.

8.3 DOE SITE INVENTORIES AND GENERATION RATES

DOE site mixed LLW cumulative mass inventories and generation rates are reported in Tables 8.2–8.9. Data are reported in these tables according to various RCRA physical and hazardous material categories. Values do not reflect any treatment that may occur prior to interim storage. Thus, some generation rates may vary from current inventory additions. Tables 8.2–8.9 report DOE site inventories and generation rates in both mass (kg) and volume (m^3) units. Until recently, many DOE sites have 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 (packaged) disposal volume. A breakdown of the site mixed LLW inventories and generation rates by various physical categories (solid, liquid, gas, sludge, and other) is provided in Tables 8.2–8.5. A breakdown of the mixed LLW volume inventory is graphically described in Fig. 8.1, and a breakdown of the volume generation level is shown in Fig. 8.2. Tables 8.6 and 8.7 give a breakdown of site mixed waste inventories according to the various types of mixed LLW previously described in Sect. 8.2. Annual generation rates are reported for these categories in Tables 8.8 and 8.9. In addition to the DOE sites previously mentioned in this report, Tables 8.2–8.9 also report data for mixed LLW at the Ames Laboratory, Ames, Iowa; Fermi National Accelerator Laboratory (FNAL), Batavia, Illinois; the Inhalation Toxicology Research Institute (ITRI), Albuquerque, New Mexico; the Kansas City Plant (KCP), Kansas City, Missouri; the Pinellas Plant, Largo, Florida; the Princeton Plasma Physics Laboratory (PPPL), Princeton, New Jersey; and the Sandia National Laboratory, Livermore, California (SNLL). Tables 8.10 and 8.11, respectively, report projected mass and volume generation rates of mixed LLW at various DOE sites. Data reported in these tables are based on information currently available. Projections from other sites will be reported in future updates of this document.

8.4 COMMERCIAL MIXED LOW-LEVEL WASTES

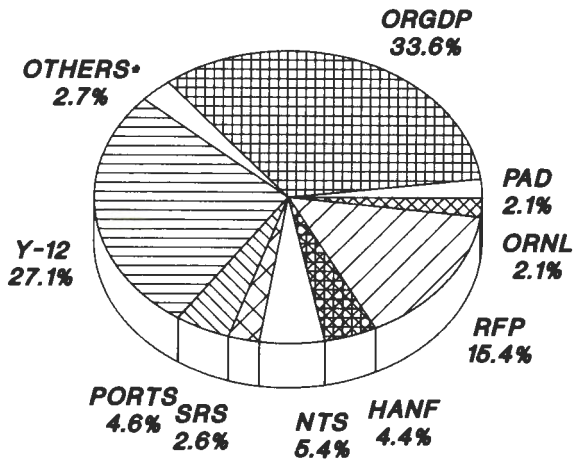
Recent projections of commercial mixed LLW are given in Table 8.12. These estimates are based on recently submitted State Governor's Certifications (ref. 8), which are required by the 1985 LLRWPAA, discussed in Chapter 4.

Several studies (refs. 9–12) have been made to identify the types, sources, volumes, and radioactivity of mixed LLW generated from commercial facilities. The most notable of these investigations is a study (ref. 12) performed by the Rogers and Associates Engineering Corporation for the Office of Technology Assessment (OTA). For this study, the total community of commercial mixed LLW generators was divided into three groups: (1) industrial facilities (including pharmaceutical manufacturing, biotechnology manufacturing, spent fuel storage, and waste processing facilities), (2) medical/academic institutions, and (3) nuclear power (LWR) plants. As a result of examining various source studies and performing surveys and interviews, the OTA study identified 12 categories of mixed LLW from these commercial facilities, institutions, and plants:

- Liquid scintillation cocktails or fluids from laboratory counting activities.
- Organic chemicals: includes residues from research and manufacturing activities, spent reagents from experiments, residues from cleaning laboratory and process equipment, and expired products.
- Trash with organic chemicals: includes used research equipment.
- Lead: includes residues and contaminated materials.
- Lead solutions from lead shielding decontamination.
- Waste oil from contaminated equipment, systems, and work areas.
- Trash with oil from radioactive systems and work areas.
- Chlorinated fluorocarbon (CFC) solvents.
- CFC concentrates from laundry and tool decontamination.
- Aqueous corrosive liquids from cleaning spent fuel casks and resin filters.
- Chromate wastes from resin changeouts in LWRs.
- Cadmium wastes from spent LWR equipment and cleanup activities: spent welding rods, weld cleaning, and equipment decontamination.

A summary of estimated annual generation characteristics of these wastes was determined in the OTA study for each of the three commercial groups investigated, and these are given in Tables 8.13–8.15. The OTA study emphasizes that, while its investigation was useful in identifying the types of commercial mixed LLW and associated management practices, it was not able to accurately determine how much of this waste is generated nationwide. Table 8.13 reports the OTA summary for mixed LLW from 35 industrial facilities (out

ORNL DWG 90-8302

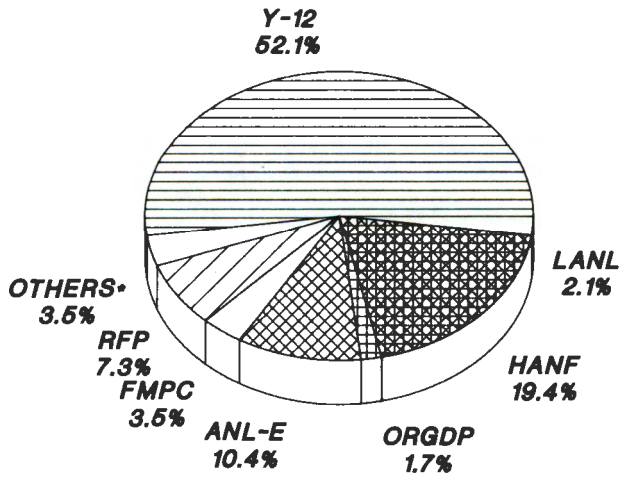


SITE	CUBIC METERS
HANF	2.45E+03
NTS	3.02E+03
ORGDP	1.88E+04
ORNL	1.20E+03
PAD	1.17E+03
PORTS	2.56E+03
RFP	8.66E+03
SRS	1.47E+03
Y-12	1.52E+04
OTHERS*	1.51E+03
TOTAL	5.60E+04

*Includes contributions from 17 sites.

Fig. 8.1. Total volume inventory of DOE mixed LLW through 1989.

ORNL DWG 90-8303



SITE	CUBIC METERS
ANL-E	8.26E+02
FMPC	2.75E+02
HANF	1.55E+03
LANL	1.64E+02
ORGDP	1.39E+02
RFP	5.79E+02
Y-12	4.15E+03
OTHERS*	2.78E+02
TOTAL	7.95E+03

*Includes contributions from 19 sites.

Fig. 8.2. Volume generation of DOE mixed LLW during 1989.

of a potential total of 563). OTA study results for mixed LLW from 39 medical/academic facilities (out of a potential total of 744) are given in Table 8.14. Summary generation characteristics of mixed LLW from 42 commercial LWRs (out of a potential total of 76) are reported in Table 8.15.

Recently, the Nuclear Management and Resources Council (NUMARC) completed a study (ref. 13) of mixed wastes in the commercial nuclear power industry. This investigation developed estimates of generation and disposal rates for mixed wastes from LWR operations (summarized in Table 8.16). Two case estimates were developed for the NUMARC study, one based on a set of conservative assumptions and the other based on reasonable changes made to those assumptions. The "reasonable assumptions" case indicates a lower bound LWR mixed waste generation rate of 82 m^3/year and a disposal rate of 21 m^3/year. These lower results are based on the following major assumptions:

- It is possible to segregate wastes containing certain hazardous (EPA code F003) spent solvents from other spent solvents.
- Characteristically hazardous wastes can be processed to render them nonhazardous.
- Procedures can be implemented to minimize radiological contamination.
- Cadmium content in welds and weld rods may be shown to not exhibit the EP toxicity characteristics.
- Explicit account can be made of the timing of mixed waste generated on an infrequent basis.
- Scintillation cocktails may be shown to not exhibit the ignitability characteristic.
- Chromate-bearing ion-exchange resins may be shown to not exhibit the EP toxicity characteristic.
- Decontamination resins may be shown to not exhibit the corrosivity characteristic.
- Individual plants may have design and operating features which do not produce the mixed waste streams assumed in this estimate.

Results of earlier studies on commercial mixed LLW, made by Brookhaven National Laboratory (refs. 9–11), indicated that about 3–10% of the total volume of commercial LLW may be mixed LLW. The upper bound of 10% could be realized if the EPA rules that waste oil should be treated as hazardous.[14] These studies also indicated that the mixed LLW portion was primarily composed of three types of hazardous materials: organic liquids, lead, and chromates. Based on the total accumulated commercial LLW disposal volume through 1989 of about 1,352,000 m^3 (see Chapter 4), a mixed waste component of 3–10% would result in about 41,000–135,000 m^3 of total mixed commercial LLW disposed nationwide. This result also suggests that from 1,400–4,600 m^3 of the nearly 46,100 m^3 of commercial LLW disposed during 1989 could have been mixed waste. It should be cautioned that the lower bound of these estimates is probably low, in part, because it does not include contributions from materials such as waste oil (listed in Tables 8.13–8.15), which in some regions of the country are considered hazardous.

8.5 REFERENCES

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

4. T. T. Traceski, DOE/HQ Office of Environmental Guidance, memo to Office of the Assistant Secretary for Environment, Safety, and Health, Director of Environmental Guidance (EH-231), "Update of States with Mixed Waste Authorization," dated July 13, 1990.

5. C. S. Fore et al., DOE Waste Information Network: DOE/DP Hazardous and Mixed Waste Data Base – A User's Guide, DOE/HP-15, Oak Ridge National Laboratory, Oak Ridge, Tennessee (August 1986).

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8. U.S. Department of Energy, Office of Environmental Restoration and Waste Management, 1989 Annual Report on Low-Level Radioactive Waste Management Progress – Report to Congress in Response to Public Law 99-240, Washington, D.C. (draft, June 1990).

9. Brookhaven National Laboratory, An Analysis of Low-Level Wastes: Review of Hazardous Waste Regulations and Identification of Radioactive Mixed Wastes, NUREG/CR-4406 (December 1985).

10. Brookhaven National Laboratory, Document Review Regarding Hazardous Chemical Characteristics of Low-Level Waste, NUREG/CR-4433 (March 1986).

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12. Rogers and Associates Engineering Corporation, Management Practices and Disposal Concepts for Low-Level Radioactive Mixed Waste, RAE-8830-1, Salt Lake City, Utah, performed for the Office of Technology Assessment, U.S. Congress, Washington, D.C. (March 1989).

13. Nuclear Management and Resources Council, The Management of Mixed Low-Level Radioactive Waste in the Nuclear Power Industry, NUMARC/NESP-006, prepared by Rogers and Associates Engineering Corporation with Nuclear Waste Management, Inc., Washington, D.C. (January 1990).

14. U.S. Congress, Office of Technology Assessment, Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste, OTA-0-426, Washington, D.C. (November 1989).

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

State/territory	Effective date	State/territory	Effective date
Arkansas	(Applied)[b]	New Mexico	(Applied)[b]
Colorado	11/07/86	North Carolina	11/21/89
Georgia	09/26/88	Ohio	06/30/89
Guam	10/10/89	Oregon	(Applied)[b]
Idaho	04/09/90	South Carolina	09/13/87
Illinois	04/30/90	Tennessee	08/11/87
Kansas	(Applied)[b]	Texas	03/15/90
Kentucky	12/19/88	Washington	11/23/87
Michigan	12/26/89	Utah	03/07/89
Minnesota	06/23/89		
		(Total = 19 states)	

[a]Based on ref. 4. Information as of May 10, 1990.
[b]Should receive authorization in the near future.

Table 8.2. Cumulative mass (kg) inventories of DOE site mixed LLW, by physical category, through 1989[a]

Site	Solid	Liquid	Gas[b]	Sludge	Other[c]	Total
Ames[d,e]	750	0	0	0	0	750
ANL-E[d,f]	56,597	48,594	0	0	0	105,191
ANL-W[d]	20,145	0	0	0	0	20,145
BNL	0	6,500	0	0	0	6,500
FMPC	548,000	267,000	0	0	0	815,000
FNAL[g]	<1	0	0	0	0	<1
HANF[h]	5,297,345	7,005	0	0	0	5,304,350
INEL	100,397	0	0	0	0	100,397
ITRI[i]	0	13,200	0	0	0	13,200
KCP[d,j]	3,647	0	0	0	0	3,647
LANL	55,205	169,143	365	40,811	93	265,617
LLNL	21,728	153,881	0	0	75,487	251,096
MOUND[k]	8,310	42,540	0	0	0	50,850
NTS	0	0	0	0	2,196,000	2,196,000
ORGDP	235,627	549,780	300	26,734,501	411,336	27,931,544
ORNL[l]	294	29,114	0	0	1,761,250	1,790,658
PAD	1,639,700	70,252	0	1,748	3,109	1,714,809
PANT	124,600	3,000	0	0	0	127,600
Pinellas[m]	0	0	0	0	6,822	6,822
PORTS	182,402	113,280	0	3,494,556	0	3,790,238
PPPL[n]	0	0	0	0	0	0
RFP	10,498,445	109,506	0	0	0	10,607,951
SNLA[k,o]	20,200	240	0	60	0	20,500
SNLL[p]	0	0	0	0	280	280
SRS[d]	808,256	669,682	0	441,600	0	1,919,538
Y-12	11,635,198	596,929	0	5,531,185	4,704,490	22,467,802
Total	31,256,846	2,849,646	665	36,244,461	9,158,867	79,510,485

[a]Materials may be in interim storage awaiting treatment.
[b]Stored in cylinders.
[c]A mixture of two or more of the solid, liquid, gas, or sludge categories.
[d]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate masses.
[e]Ames Laboratory (operated by Iowa State University) at Ames, Iowa.
[f]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.
[g]Fermi National Accelerator Laboratory at Batavia, Illinois.
[h]HANF inventories include only 1987, 1988, and 1989 data.
[i]Inhalation Toxicology Research Institute, Kirtland Air Force Base, Albuquerque, New Mexico.
[j]Kansas City Plant operated by Allied-Signal Inc., Kansas City Division, Kansas City, Missouri.
[k]Data reported for 1988. Updated information for 1989 was not available.
[l]Includes a small contribution from Oak Ridge Associated Universities (ORAU).
[m]Pinellas Plant (operated by the General Electric Company), Largo, Florida.
[n]Princeton Plasma Physics Laboratory at Princeton, New Jersey.
[o]Sandia National Laboratory at Albuquerque, New Mexico.
[p]Sandia National Laboratory at Livermore, California.

Table 8.3. Cumulative volume (m^3) inventories of DOE site mixed LLW, by physical category, through 1989[a]

Site	Solid	Liquid	Gas[b]	Sludge	Other[c]	Total
Ames	0.5	0	0	0	0	0.5
ANL-E[d]	37.7	42.3	0	0	0	80
ANL-W	13.43	0	0	0	0	13.43
BNL	0	6.5	0	0	0	6.5
FMPC	342	200	0	0	0	542
FNAL	2.09	0	0	0	0	2.09
HANF[e]	2,450.2	3.2	0	0	0	2,453.4
INEL	74.12	0	0	0	0	74.12
ITRI	0	28.8	0	0	0	28.8
KCP	4.83	0	0	0	0	4.83
LANL	62.7	190.2	0.5	38.8	0	292.2
LLNL	21.7	153.9	0	0	75.5	251.1
MOUND[f]	5.6	42.5	0	0	0	48.1
NTS	0	0	0	0	3,019	3,019
ORGDP[g]	157.1	549.8	0.6	17,823.0	274.2	18,804.7
ORNL[g,h]	0.20	29.11	0	0	1,174.16	1,203.47
PAD[g]	1,093.1	70.3	0	1.1	2.1	1,166.6
PANT	85.5	3	0	0	0	88.5
Pinellas	0	0	0	0	6.47	6.47
PORTS[g]	121.6	113.3	0	2,329.7	0	2,564.6
PPPL	0	0	0	0	0	0
RFP	8,529.9	127.8	0	0	0	8,657.7
SNLA[f]	68.5	1.2	0	0.3	0	70.0
SNLL	0	0	0	0	0.29	0.29
SRS	539.2	558.8	0	368.0	0	1,466.0
Y-12[g]	7,756.8	596.9	0	3,687.5	3,136.3	15,177.5
Total	21,366.77	2,717.61	1.1	24,248.4	7,688.02	56,021.90

[a]Materials may be in interim storage awaiting treatment.
[b]Stored in cylinders.
[c]A mixture of two or more of the solid, liquid, gas, or sludge categories.
[d]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.
[e]HANF inventories include only 1987, 1988, and 1989 data and are based on a density of 2,162 kg/m^3.
[f]Data reported for 1988. Updated information for 1989 was not available.
[g]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate volumes.
[h]Includes a small contribution from ORAU.

Table 8.4. Mass generation rates (kg/year) of DOE site mixed LLW, by physical category, for 1989[a]

Site	Solid	Liquid	Gas[b]	Sludge	Other[c]	Total
Ames[d]	0	0	0	0	0	0
ANL-E[d,e]	1,654	825,221	0	0	0	826,875
ANL-W[d]	300	0	0	0	0	300
BNL	0	4,300	0	0	0	4,300
FMPC	223,000	203,800	0	0	0	426,800
FNAL	0	0	0	0	0	0
HANF	3,341,925	1,539	0	0	0	3,343,464
INEL	65,592	0	0	0	0	65,592
ITRI	0	460	0	0	0	460
KCP[d]	454	0	0	0	0	454
LANL	28,168	86,652	85	33,797	0	148,702
LLNL	5,408	27,058	0	0	43,467	75,933
MOUND	f	f	f	f	f	f
NTS	0	0	0	0	0	0
ORGDP	49,606	43,333	0	16,790	77,725	187,454
ORNL[g]	36	2,392	0	0	15,465	17,893
PAD	19,426	14,626	0	1,748	2,654	38,454
PANT	90	0	0	0	0	90
Pinellas	0	0	0	0	0	0
PORTS	51,235	9,404	0	44,025	0	104,664
PPPL	0	0	0	0	0	0
RFP	646,845	15,333	0	0	0	662,178
SNLA	f	f	f	f	f	f
SNLL	0	4	0	0	280	284
SRS[d]	64,742	1,631	0	0	0	66,373
Y-12	198,394	157,905	0	1,080,835	4,704,490	6,141,624
Total	4,696,875	1,393,658	85	1,177,195	4,844,081	12,111,894

[a]Values do not reflect any treatment that may, or will, occur prior to interim storage.
[b]Stored in cylinders.
[c]A mixture of two or more of the solid, liquid, gas, or sludge categories.
[d]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate masses.
[e]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.
[f]Information not available.
[g]Includes a small contribution from ORAU.

Table 8.5. Volume generation rates (m^3/year) of DOE site mixed LLW, by physical category, for 1989[a]

Site	Solid	Liquid	Gas[b]	Sludge	Other[c]	Total
Ames	0	0	0	0	0	0
ANL-E[d]	2	824	0	0	0	826
ANL-W	0.20	0	0	0	0	0.20
BNL	0	4.3	0	0	0	4.3
FMPC	139	136	0	0	0	275
FNAL	0	0	0	0	0	0
HANF[e]	1,545.8	0.7	0	0	0	1,546.5
INEL	32.23	0	0	0	0	32.23
ITRI	0	1	0	0	0	1
KCP	1.05	0	0	0	0	1.05
LANL	30.9	95.3	0.2	37.1	0	163.5
LLNL	5.4	27.0	0	0	43.5	75.9
MOUND	f	f	f	f	f	f
NTS	0	0	0	0	0	0
ORGDP[g]	33.1	43.3	0	11.2	51.8	139.4
ORNL[g,h]	0.02	2.39	0	0	10.31	12.72
PAD[g]	12.95	14.63	0	1.17	1.76	30.51
PANT	2.55	0	0	0	0	2.55
Pinellas	0	0	0	0	0	0
PORTS[g]	34.1	9.4	0	29.4	0	72.9
PPPL	0	0	0	0	0	0
RFP	560.8	17.9	0	0	0	578.7
SNLA	f	f	f	f	f	f
SNLL	0	0.004	0	0	0.27	0.274
SRS	43.25	1.50	0	0	0	44.75
Y-12[g]	132.3	157.9	0	720.6	3,136.3	4,147.1
Total	2,575.65	1,335.324	0.2	799.47	3,243.94	7,954.584

[a]Values do not reflect any treatment that may, or will, occur prior to interim storage.
[b]Stored in cylinders.
[c]A mixture of two or more of the solid, liquid, gas, or sludge categories.
[d]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.
[e]Based on a density of 2,162 kg/m^3.
[f]Information not available.
[g]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate volumes.
[h]Includes a small contribution from ORAU.

Table 8.6. Cumulative mass (kg) inventories of DOE site mixed LLW, by hazard category, through 1989[a]

Site	Ignitable	Corrosive	EP toxic	Spent solvents	Spent sludges	Discarded chemicals	PCBs	Other[b]	Total
Ames[c]	0	0	750	0	0	0	0	0	750
ANL-E[c,d]	2,701	0	53,896	48,594	0	0	0	0	105,191
ANL-W[c]	0	0	1,695	150	0	0	0	18,300	20,145
BNL	0	0	0	6,500	0	0	0	0	6,500
FMPC	21,000	698	591,000	198,000	0	2	4,300	0	815,000
FNAL	0	0	0	0	0	0	0	<1	<1
HANF[e]	1,046,770	19,382	1,269,426	28,878	0	991,559	7,600	1,940,735	5,304,350
INEL	0	0	100,397	0	0	0	0	0	100,397
ITRI	13,200	0	0	0	0	0	0	0	13,200
KCP[c]	0	0	1,563	2,084	0	0	0	0	3,647
LANL	34,400	2,166	22,144	58,301	0	93	5,039	143,474	265,617
LLNL	1,180	68,374	76,723	85,090	0	14	0	19,715	251,096
MOUND[f]	13,000	0	3,100	0	0	26,000	8,750	0	50,850
NTS	0	0	0	2,196,000	0	0	0	0	2,196,000
ORGDP	35,746	203,663	120,457	400,926	26,732,961	18,652	419,139[g]	0	27,931,544
ORNL[h]	12,401	4,015	377	9,077	0	652	3,312	1,760,824	1,790,658
PAD	1,006	4,721	20,596	41,653	0	0	1,646,833	0	1,714,809
PANT	0	0	48,000	0	0	79,600	0	0	127,600
Pinellas	0	0	6,822	0	0	0	0	0	6,822
PORTS	3,298	4,592	377,502	2,697,998	0	47	i	706,801	3,790,238
PPPL	0	0	0	0	0	0	0	0	0
RFP	0	6,781	24,663	10,571,724	2,535	1,150	1,098	0	10,607,951
SNLA[f]	0	0	16,000	0	0	0	0	4,500	20,500
SNLL	280	0	0	0	0	0	0	0	280
SRS[c]	3,750	0	353,163	113,625	1,449,000	0	0	0	1,919,538
Y-12	21,071	5,989	10,771,976	329,614	5,390,117	0	5,946,615	2,420	22,467,802
Total	1,209,803	320,381	13,860,250	16,788,214	33,574,613	1,117,769	8,042,686	4,596,769	79,510,485

[a]Material may be in interim storage awaiting treatment.
[b]Other refers to mixed wastes whose major hazardous component is not otherwise categorized. Examples are reactives, poisons, and carcinogens.
[c]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate masses.
[d]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.
[e]HANF inventories include only 1987, 1988, and 1989 data.
[f]Data reported for 1988. Updated information for 1989 was not available.
[g]Excludes 3,500,000 kg of PCB-contaminated soil from PORTS.
[h]Includes a small contribution from ORAU.
[i]Information not available.

Table 8.7. Cumulative volume (m^3) inventories of DOE site mixed LLW, by hazard category, through 1989[a]

Site	Ignitable	Corrosive	EP toxic	Spent solvents	Spent sludges	Discarded chemicals	PCBs	Other[b]	Total
Ames	0	0	0.5	0	0	0	0	0	0.5
ANL-E[c]	1.8	0	35.9	42.3	0	0	0	0	80
ANL-W	0	0	1.13	0.1	0	0	0	12.2	13.43
BNL	0	0	0	6.5	0	0	0	0	6.5
FMPC	15	<1	387	130	0	<1	10	0	542
FNAL	0	0	0	0	0	0	0	2.09	2.09
HANF[d]	484.2	8.9	587.1	13.4	0	458.6	3.5	897.7	2,453.4
INEL	0	0	74.12	0	0	0	0	0	74.12
ITRI	28.8	0	0	0	0	0	0	0	28.8
KCP	0	0	2.08	2.75	0	0	0	0	4.83
LANL	63.9	2.1	51.5	124.2	0	0.4	1.7	48.4	292.2
LLNL	1.2	68.4	76.7	85.1	0	0.02	0	19.68	251.1
MOUND[e]	13	0	2.1	0	0	26	7	0	48.1
NTS	0	0	0	3,019	0	0	0	0	3,019
ORGDP[f]	28.7	194.6	119.9	341.4	17,822.0	18.7	279.4	0	18,804.7
ORNL[f,g]	12.38	4.01	0.25	9.08	0	0.65	3.22	1,173.88	1,203.47
PAD[f]	1	3.2	13.7	41.7	0	0	1,107.0	0	1,166.6
PANT	0	0	32	0	0	56.5	0	0	88.5
Pinellas	0	0	6.47	0	0	0	0	0	6.47
PORTS[f]	3.3	4.6	282.1	1,801.1	0	0.05	h	473.45	2,564.6
PPPL	0	0	0	0	0	0	0	0	0
RFP	0	7.1	36.1	8,604	2.5	1.3	6.7	0	8,657.7
SNLA[e]	0	0	35	0	0	0	0	35	70
SNLL	0.29	0	0	0	0	0	0	0	0.29
SRS	3.8	0	235.7	76.5	1,150.0	0	0	0	1,466.0
Y-12[f]	21.1	6.0	7,181.3	329.6	3,593.4	0	4,044.5	1.6	15,177.5
Total	678.47	298.91	9,160.65	14,626.73	22,567.90	562.22	5,463.02	2,664.00	56,021.90

[a]Material may be in interim storage awaiting treatment.

[b]Other refers to mixed wastes whose major hazardous component is not otherwise categorized. Examples are reactives, poisons, and carcinogens.

[c]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.

[d]HANF inventories include only 1987, 1988, and 1989 data and are based on a density of 2,162 kg/m^3.

[e]Data reported for 1988. Updated information for 1989 was not available.

[f]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate volumes.

[g]Includes a small contribution from ORAU.

[h]Information not available.

Table 8.8. Mass generation rates (kg/year) of DOE site mixed LLW, by hazard category, for 1989[a]

Site	Ignitable	Corrosive	EP toxic	Spent solvents	Spent sludges	Discarded chemicals	PCBs	Other[b]	Total
Ames[c]	0	0	0	0	0	0	0	0	0
ANL-E[c,d]	0	825,221	1,654	0	0	0	0	0	826,875
ANL-W[c]	0	0	300	0	0	0	0	0	300
BNL	0	0	0	4,300	0	0	0	0	4,300
FMPC	5,500	0	352,000	65,000	0	0	4,300	0	426,800
FNAL	0	0	0	0	0	0	0	0	0
HANF	3,286	1,774	877,941	18,801	0	545,500	7,600	1,888,562	3,343,464
INEL	0	0	65,592	0	0	0	0	0	65,592
ITRI	460	0	0	0	0	0	0	0	460
KCP[c]	0	0	454	0	0	0	0	0	454
LANL	7,620	793	13,403	48,281	0	0	0	78,605	148,702
LLNL	1,020	3,751	30,563	22,890	0	14	0	17,695	75,933
MOUND	e	e	e	e	e	e	e	e	e
NTS	0	0	0	0	0	0	0	0	0
ORGDP	11,076	20,878	0	64,643	16,790	0	74,067	0	187,454
ORNL[f]	1,626	228	104	1,090	0	0	1,110	13,735	17,893
PAD	162	4,034	5,483	6,726	0	0	22,049	0	38,454
PANT	0	0	0	0	0	90	0	0	90
Pinellas	0	0	0	0	0	0	0	0	0
PORTS	0	0	75,227	29,437	0	0	e	e	104,664
PPPL	0	0	0	0	0	0	0	0	0
RFP	0	380	1,318	659,750	0	730	0	0	662,178
SNLA	e	e	e	e	e	e	e	e	e
SNLL	280	0	0	0	4	0	0	0	284
SRS[c]	750	0	29,243	36,380	0	0	0	0	66,373
Y-12	4,332	5,091	7,140	17,885	728,275	0	5,030,296	348,605	6,141,624
Total	36,112	862,150	1,460,422	975,183	745,069	546,334	5,139,422	2,347,202	12,111,894

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

[b]Other refers to mixed wastes whose major hazardous component is not otherwise categorized. Examples are reactives, poisons, and carcinogens.

[c]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate masses.

[d]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.

[e]Information not available.

[f]Includes a small contribution from ORAU.

Table 8.9. Volume generation rates (m^3/year) of DOE site mixed LLW, by hazard category, for 1989[a]

Site	Ignitable	Corrosive	EP toxic	Spent solvents	Spent sludges	Discarded chemicals	PCBs	Other[b]	Total
Ames	0	0	0	0	0	0	0	0	0
ANL-E[c]	0	824	2	0	0	0	0	0	826
ANL-W	0	0	0.2	0	0	0	0	0	0.20
BNL	0	0	0	4.3	0	0	0	0	4.3
FMPC	4	0	220	41	0	0	10	0	275
FNAL	0	0	0	0	0	0	0	0	0
HANF[d]	1.5	0.8	406.1	8.7	0	252.3	3.5	873.6	1,546.5
INEL	0	0	32.23	0	0	0	0	0	32.23
ITRI	1	0	0	0	0	0	0	0	1
KCP	0	0	1.05	0	0	0	0	0	1.05
LANL	8.4	0.9	14.7	53.1	0	0	0	86.4	163.5
LLNL	1.02	3.7	30.58	22.9	0	0	0.02	17.68	75.9
MOUND	e	e	e	e	e	e	e	e	e
NTS	0	0	0	0	0	0	0	0	0
ORGDP[f]	8.6	20.9	0	49.3	11.2	0	49.4	0	139.4
ORNL[f,g]	1.08	0.23	0.07	1.09	0	0	1.10	9.15	12.72
PAD[f]	0.16	4.03	3.66	6.73	0	0	15.93	0	30.51
PANT	0	0	0	0	0	2.55	0	0	2.55
Pinellas	0	0	0	0	0	0	0	0	0
PORTS[f]	0	0	53.3	19.6	0	0	f	f	72.9
PPPL	0	0	0	0	0	0	0	0	0
RFP	0	0.4	3.4	574.1	0	0.8	0	0	578.7
SNLA	e	e	e	e	e	e	e	e	e
SNLL	0.27	0	0	0	0.004	0	0	0	0.274
SRS	0.75	0	19.5	24.5	0	0	0	0	44.75
Y-12[f]	4.3	5.1	4.8	17.9	485.5	0	3,397.1	232.4	4,147.1
Total	31.08	860.06	791.59	823.22	496.704	255.65	3,477.05	1,219.23	7,954.584

[a]Material may be in interim storage awaiting treatment.

[b]Other refers to mixed wastes whose major hazardous component is not otherwise categorized. Examples are reactives, poisons, and carcinogens.

[c]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.

[d]Based on a density of 2,162 kg/m^3.

[e]Information not available.

[f]Densities of 1,000 kg/m^3 for liquids, 500 kg/m^3 for gases, and 1,500 kg/m^3 for solids, sludges, and others were assumed to calculate volumes.

[g]Includes a small contribution from ORAU.

Table 8.10. Projected annual mixed LLW mass generation rates (kg/year) for various DOE sites

Site	Calendar year(s)					
	1990	1991	1992	1993	1994	1995-2020
ANL-E[a]	826,875	826,875	750,000	750,000	750,000	640,000
HANF	2,433,662	1,670,674	821,835	913,534	450,077	528,411
INEL	19,014	19,014	19,014	19,014	16,014	16,014
ITRI	460	460	460	460	460	460
KCP	316	316	1,586	316	316	316
LLNL	75,933	75,933	75,933	75,933	75,933	75,933
Pinellas	0	0	0	0	0	0
RFP	4,207,663	4,207,663	662,178	662,178	662,178	662,178
SNLL	4	4	4	4	4	4
SRS	389,610	389,610	589,610	2,749,610	2,749,610	2,749,610
Total	7,953,537	7,190,549	2,920,620	5,171,049	4,704,592	4,672,926

[a]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.

Table 8.11. Projected annual mixed LLW volume generation rates (m^3/year) for various DOE sites

Site	Calendar year(s)					
	1990	1991	1992	1993	1994	1995-2020
ANL-E[a]	826	826	745	745	745	635
HANF	1,125.4	772.6	380.0	422.5	208.1	244.4
INEL	12.5	12.5	12.5	12.5	9.3	9.3
ITRI	1	1	1	1	1	1
KCP	0.4	0.4	1.7	0.4	0.4	0.4
LLNL	75.9	75.9	75.9	75.9	75.9	75.9
Pinellas	0	0	0	0	0	0
RFP	3,314.7	3,314.7	578.7	578.7	578.7	578.7
SNLL	0.2	0.2	0.2	0.2	0.2	0.2
SRS	289.4	289.4	489.4	1,929.4	1,929.4	1,924.4
Total	5,645.5	5,292.7	2,284.4	3,765.6	3,548.0	3,474.3

[a]At press time, ANL-E data were being revised significantly downward as a result of waste stream analysis and reclassification. These revised data will be documented in the 1991 Integrated Data Base report.

Table 8.12. Projections of commercial mixed LLW volumes after 1992[a]

Compact/states	Projected volume (m^3)[b]			
	1993	1994	1995	Total
Appalachian	31	35	38	104
Central[c]	-	-	-	-
Central-Midwest	(51)	(51)	(51)	(153)
District of Columbia	(117)	-	-	(117)
Maine	-	-	-	-
Massachusetts[d]	(142)	(142)	(142)	(426)
Midwest	(86)	(86)	(86)	(258)
New Hampshire	-	-	-	-
New York[e]	-	-	-	-
Northeast				
New Jersey	(1)	(1)	(1)	(3)
Connecticut	(174)	(174)	-	(348)
Northwest[f]	-	-	-	-
Puerto Rico	-	-	-	-
Rhode Island	-	-	-	-
Rocky Mountain[f]	-	-	-	-
Southeast[f]	173	173	173	519
Texas	-	-	-	-
Vermont	-	-	-	-
Western[f]	-	-	-	-
Total[g]	775	662	491	1928

[a]Based on State Governor's Certifications reported in ref. 8.

[b]Volumes without parentheses reflect waste that has undergone some form of volume reduction; volumes in parentheses reflect waste that has not undergone volume reduction.

[c]The Central Compact did not distinguish between LLW and mixed LLW volumes, but indicated that access to disposal will be provided by January 1, 1993.

[d]Based on 1989 mixed LLW inventory.

[e]New York did not report mixed LLW data in ref. 8.

[f]These compacts/states did not need to submit a State Governor's Certification for ref. 8 because they were either already sited or their license application had been submitted.

[g]Includes contributions from both treated and untreated wastes.

Table 8.13. OTA study: summary of estimated characteristics of annually generated mixed LLW from industrial facilities[a]

(Information for 35 out of a potential 563 industrial facilities)[b]

Type of mixed LLW	Volume (m^3/year)	Specific activity (Ci/m^3)	Radionuclides identified in waste(s)
Liquid scintillation cocktails or fluids	17.0[c]	0.00071-0.092	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{45}Ca, ^{51}Cr, ^{125}I, and ^{131}I
Organic chemicals	93[d]	0.035-110	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{60}Co, ^{90}Sr, ^{125}I, ^{137}Cs, and ^{241}Am
Trash contaminated with organic chemicals	0.6	0.007	^{3}H, ^{14}C, ^{32}P, and ^{125}I
Lead	0[e]	f	Mixed fission products[f]
Lead decontamination solutions	3	f	Mixed fission products[f]
CFC concentrates	6	0.000011	f
Aqueous corrosive liquid	91[g]	99	Mixed activation products[f]
Waste oil	4.87	0.00007	^{3}H, ^{14}C, ^{60}Co, ^{99}Tc, ^{134}Cs, and ^{137}Cs
Reactive chemicals (uranyl nitrate and thorium nitrate)	6.68	0.0019	Uranium and thorium radionuclides
Other[h]	77.9	0.-53	f
Total (35 facilities)	300		

[a]Based on the information reported in ref. 12.

[b]The information reported should be considered rough estimates because of possible double-counting (duplication of data) and provision of incomplete facility data in the surveys taken for this study.

[c]Waste processors report a total scintillation fluid volume of 2920 m^3 from all types of generators.

[d]Does not include 25 m^3 in storage.

[e]Does not include 2.6 to 3.5 m^3 in storage. Most of this waste has very low activity, although about 0.5 m^3 may be GTCC waste.

[f]Detailed information not available.

[g]Does not include 1100 m^3 in storage.

[h]Waste reported as mixed but lacking sufficient information to determine type.

Table 8.14. OTA study: summary of estimated characteristics of annually generated mixed LLW from medical/academic facilities[a]

(Information for 39 out of a potential 744 medical/academic facilities)[b]

Type of mixed LLW	Volume (m^3/year)	Specific activity (Ci/m^3)	Radionuclides identified in waste(s)
Liquid scintillation cocktails or fluids	516.08[c]	0.0003-0.0042	^{14}C, ^{22}Na, ^{32}P, ^{35}S, ^{36}Cl, ^{45}Ca, ^{46}Sc, ^{51}Cr, ^{57}Co, ^{63}Ni, ^{85}Sr, ^{86}Rb, ^{111}In, ^{125}I, ^{131}I, ^{141}Ce, ^{153}Gd, and ^{203}Pb
Organic chemicals	15.9-16.4[d]	0.000007-1.3	^{3}H, ^{14}C, and ^{35}S
Lead	0.6[e]	0.053	Radium radionuclides and standard radionuclides used by medical facilities and universities
Waste oil	0[f]	>0.00004	^{3}H
Reactive chemicals	0.003	0.13	Uranium and thorium radionuclides
Other[g]	41.54	0.004-0.1	h
Total (39 facilities)	574.1-574.6		

[a]Based on the information reported in ref. 12.
[b]The information reported should be considered rough estimates because of possible double-counting (duplication of data) and provision of incomplete facility data in the surveys taken for this study.
[c]Waste processors report a total scintillation fluid volume of 2920 m^3 from all types of generators.
[d]Does not include 4.64 m^3 in storage.
[e]Does not include 6.85 m^3 in storage.
[f]Does not include 0.8 m^3 in storage.
[g]Waste reported as mixed but lacking sufficient information to determine type.
[h]Detailed information not available.

Table 8.15. OTA study: summary of estimated characteristics of annually generated mixed LLW from commercial LWR power plants[a]

(Information for 42 out of a potential 76 LWR power plants)[b]

Type of mixed LLW	Volume (m^3/year)	Specific activity (Ci/m^3)	Radionuclides identified in waste(s)
Liquid scintillation cocktails or fluids	3.28	0–0.046	c
Organic chemicals	5.86[d,e]	c	c
Waste oil	715.77[f]	0.007	^{3}H, ^{14}C, ^{54}Mn, ^{51}Cr, ^{55}Fe, ^{59}Fe, ^{58}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{90}Sr, ^{99}Tc, ^{125}Sb, ^{129}I, ^{134}Cs, and ^{137}Cs
CFC solvents and concentrates	204.8[g]	0–0.00039	c
Low-activity sludge	0[h]	c	c
Chromium/cadmium waste	1.3	0–0.46	c
Lead	1.5	0.14	c
Ignitable	0.54	0.002	c
Corrosive	0.2	0.004	c
Other[i]	38.2[j]	0.081	c
Total (42 facilities)	971.5		

[a]Based on the information reported in ref. 12.
[b]The information reported should be considered rough estimates because of possible double-counting (duplication of data) and provision of incomplete facility data in the surveys taken for this study.
[c]Detailed information not available.
[d]<0.03 m^3 reported in storage.
[e]May include some CFC solvents.
[f]Does not include 6.8 m^3 in storage.
[g]May include other halogenated solvents.
[h]Does not include 850 m^3 resulting from a one-time event.
[i]Includes either toxic waste or a combination of lead, CFC waste, liquid scintillation fluids, cleaning solvents, and other unspecified materials.
[j]Does not include 47.80 m^3 in storage.

Table 8.16. NUMARC study: summary of estimated characteristics of mixed LLW from commercial LWR operations[a]

Source	Annual waste volume (m^3/year)	
	Generated	Disposed
BWR operations	119	59.5
PWR operations	102	42.5
LWR total (Conservative base case)	221	102
(Reasonable assumptions case)	82.1	21.2

[a]Based on the NUMARC study of ref. 13.

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

APPENDIX A. WASTE FLOWSHEETS, SOURCE TERMS, AND CHARACTERISTICS

A.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 2020. Many of these involve parameters that characterize certain types of waste (e.g., see Table A.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 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 A.1 through A.9 were taken from refs. 1 and 2. Figure A.10 was adapted from information presented in ref. 3. Table A.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. A.1–A.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 A.3. The mass, radioactivity, and thermal power of the nuclides contained in all stored domestic commercial LWR spent fuel as of December 31, 1989, are listed in Table A.4.

Representative DOE LLW radionuclide compositions are described in Table A.5 (based on ref. 1). Average concentrations for representative radionuclides in LLW disposed of at commercial sites are given in Table A.6, which is based on data available in ref. 1. Table A.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 A.8, which is based on refs. 7, 9, and 10. Table A.9 is a compilation of irradiated core component data extracted from semiannual reports to the NRC by nuclear power plants from 1959 through 1989.[7,8] 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 A.10, which is taken from ref. 11.

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

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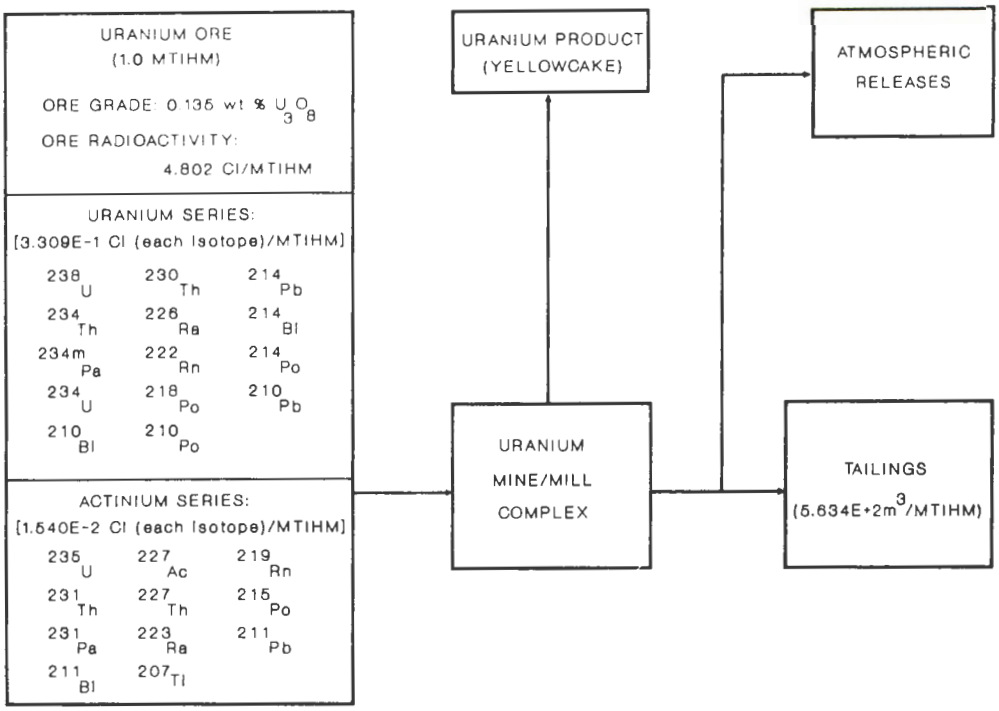
ORNL DWG 89-7803



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	1.000E+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. A.1. Principal waste and product streams from a uranium mine/mill complex.

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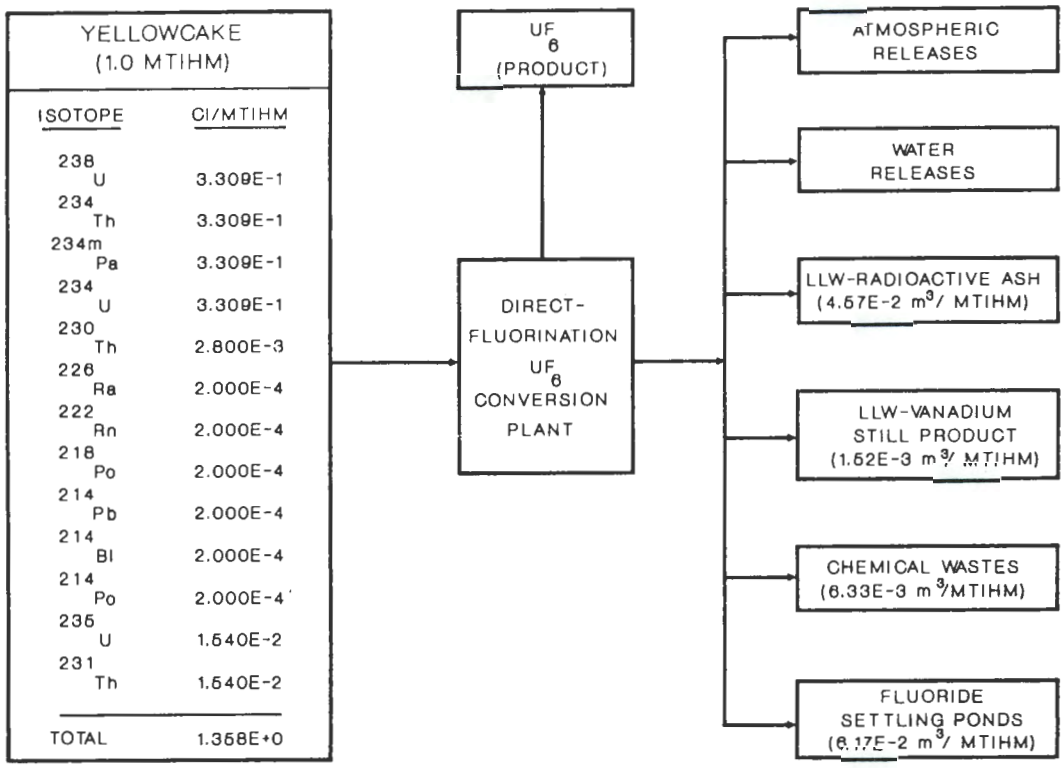
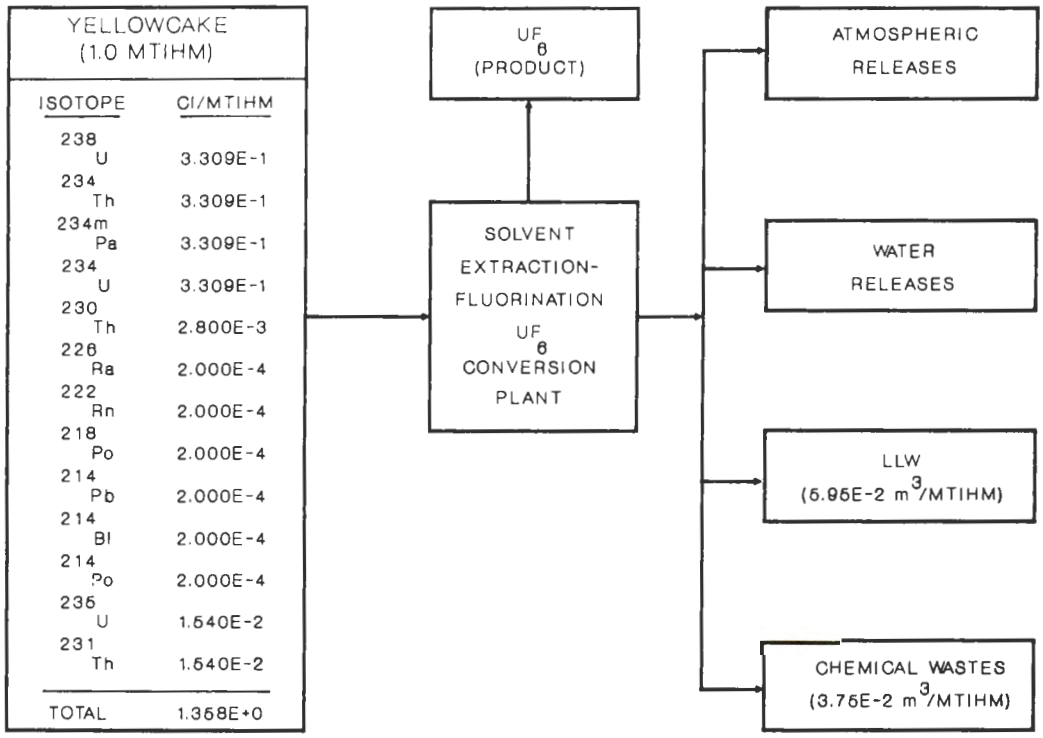


Fractions of elements from yellowcake in waste and product streams from a direct-fluorination UF_6 conversion plant

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

ORNL DWG 89-7805

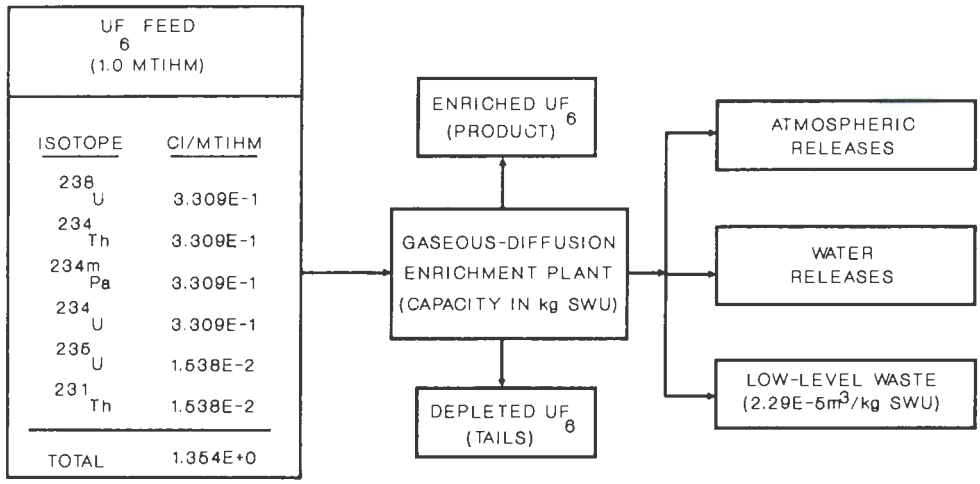


Fractions of elements from yellowcake in waste and product streams from a solvent extraction-fluorination UF_6 conversion plant

	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	1.15E-11	1.00E+0	2.25E-6	0.00

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

ORNL DWG 89-7806



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

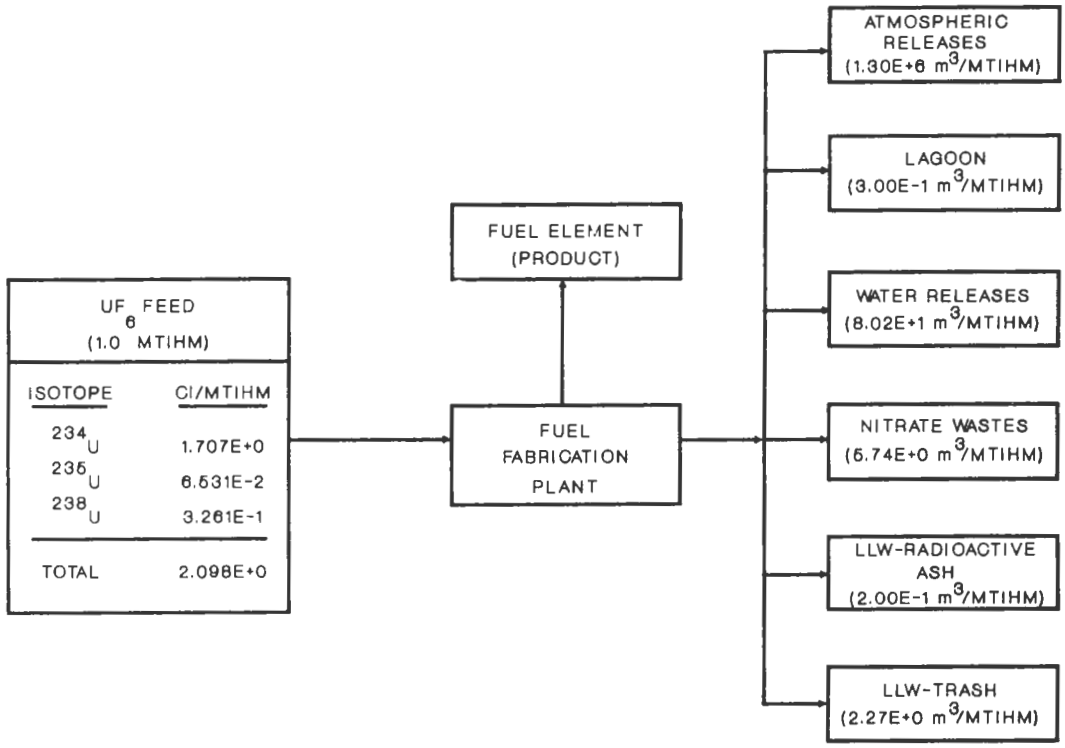
Product desired enrichment (wt % ^{235}U)	Feed natural (0.711 wt % ^{235}U) uranium (kg)	Separative work units (No. of kg SWU)
2	3.523	2.194
3	5.479	4.306
4	7.436	6.544

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. A.4. Principal waste and product streams from a gaseous-diffusion uranium enrichment plant.

ORNL DWG 89-7807

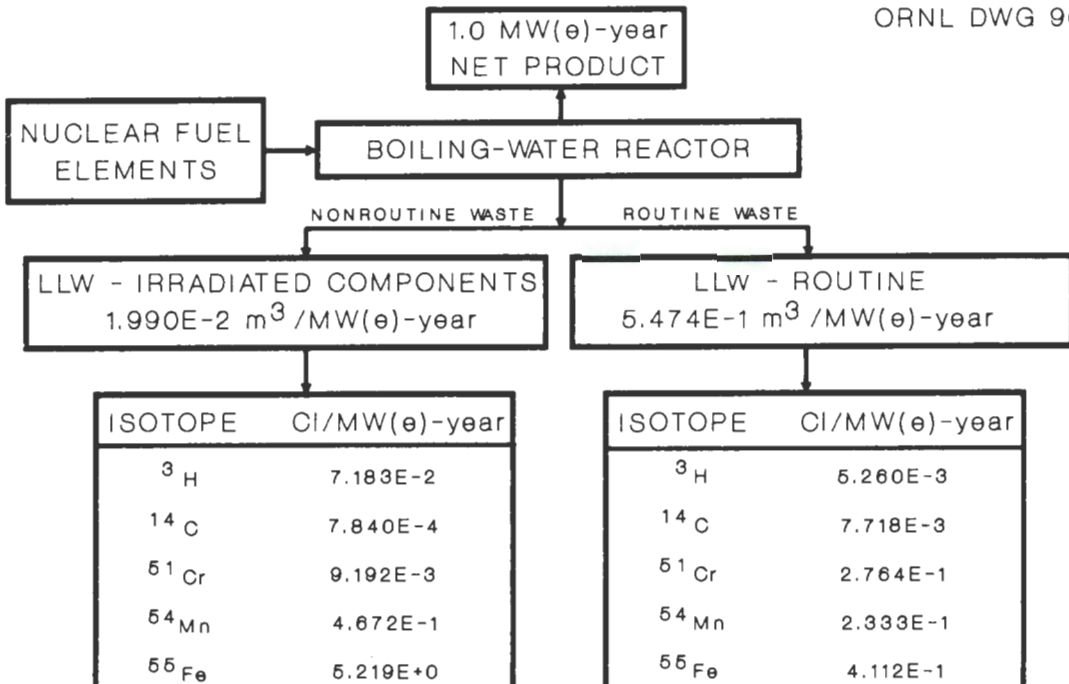


Fractions of uranium from feed in waste and product streams from a fuel fabrication plant

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

ORNL DWG 90-8309



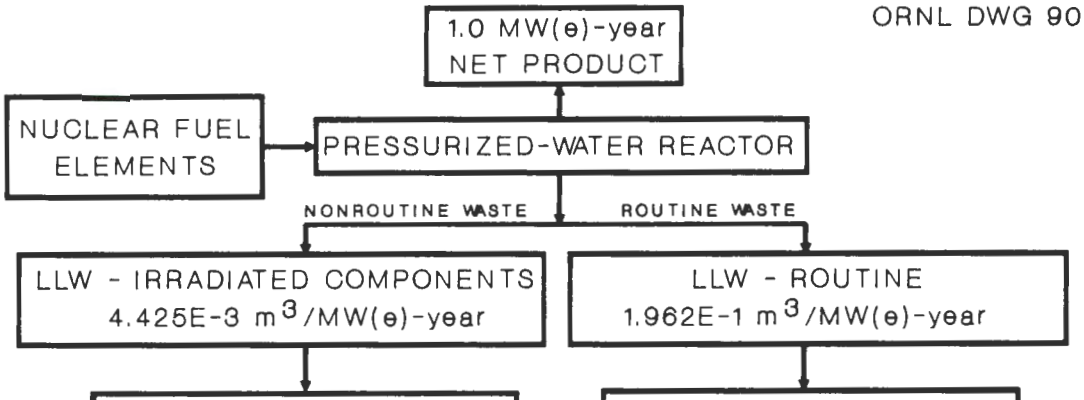
ISOTOPE	Ci/MW(e)-year
^{3}H	7.183E-2
^{14}C	7.840E-4
^{51}Cr	9.192E-3
^{54}Mn	4.672E-1
^{55}Fe	5.219E+0
^{58}Co	1.458E-1
^{59}Fe	2.105E-4
^{59}Ni	6.592E-3
^{60}Co	7.302E+0
^{63}Ni	6.713E-1
^{65}Zn	3.255E-3
^{90}Sr	2.712E-5
^{90}Y	2.712E-5
^{94}Nb	7.703E-6
^{99}Tc	1.587E-4
^{129}I	4.965E-5
^{134}Cs	3.041E-3
^{137}Cs	2.523E-3
^{137m}Ba	2.449E-3
^{241}Pu	1.647E-4
^{242}Cm	1.586E-4
TOTAL	1.391E+1

ISOTOPE	Ci/MW(e)-year
^{3}H	5.260E-3
^{14}C	7.718E-3
^{51}Cr	2.764E-1
^{54}Mn	2.333E-1
^{55}Fe	4.112E-1
^{58}Co	6.076E-2
^{59}Fe	1.532E-2
^{59}Ni	2.080E-4
^{60}Co	1.067E+0
^{63}Ni	2.545E-2
^{65}Zn	2.618E-1
^{90}Sr	1.299E-3
^{90}Y	1.299E-3
^{94}Nb	7.916E-6
^{99}Tc	8.963E-5
^{129}I	8.598E-4
^{134}Cs	1.400E-1
^{137}Cs	1.708E-1
^{137m}Ba	1.616E-1
^{144}Ce	6.758E-4
^{144}Pr	6.758E-4
^{241}Pu	1.382E-3
^{242}Cm	2.581E-5
TOTAL	2.843E+0

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

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

ORNL DWG 90-8310



ISOTOPE	Ci/MW(e)-year
^{3}H	8.768E-3
^{14}C	1.837E-5
^{51}Cr	7.863E-3
^{54}Mn	7.538E-2
^{55}Fe	5.547E-1
^{58}Co	2.113E-1
^{59}Fe	3.894E-4
^{60}Co	9.840E-1
^{63}Ni	1.209E-1
^{65}Zn	2.480E-7
^{90}Sr	1.879E-5
^{90}Y	1.879E-5
^{94}Nb	3.426E-8
^{134}Cs	3.170E-2
^{137}Cs	5.434E-2
^{137m}Ba	5.140E-2
^{144}Ce	1.266E-7
^{144}Pr	1.266E-7
TOTAL	2.101E+0

ISOTOPE	Ci/MW(e)-year
^{3}H	2.319E-2
^{14}C	1.432E-3
^{51}Cr	3.580E-3
^{54}Mn	2.207E-2
^{55}Fe	6.426E-2
^{58}Co	1.747E-1
^{59}Fe	5.306E-4
^{59}Ni	2.337E-4
^{60}Co	2.545E-1
^{63}Ni	1.151E-1
^{65}Zn	1.263E-4
^{90}Sr	3.467E-2
^{90}Y	3.467E-2
^{94}Nb	1.544E-6
^{99}Tc	7.612E-5
^{129}I	1.696E-5
^{134}Cs	1.032E-1
^{137}Cs	1.272E-1
^{137m}Ba	1.204E-1
^{144}Ce	5.837E-4
^{144}Pr	5.837E-4
^{241}Pu	7.591E-4
^{242}Cm	1.268E-4
TOTAL	1.082E+0

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

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

ORNL DWG 89-7810

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

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 = 4.07E-2 m^3/MW(e)

TOTAL ACTIVITY = 5.29E+3 Ci/MW(e)

	GREATER THAN CLASS C
Volume, m^3/MW(e)	4.07E-2
Activity, Ci/MW(e)	5.29E+3
Specific Activity, Ci/m^3	
^{14}C	5.00E+0
^{59}Ni	3.00E+1
^{94}Nb	7.10E-2
^{99}Tc	1.50E-3
^{60}Co	1.60E+4
^{63}Ni	4.20E+3
Half-Life <5 yr	1.10E+5
Total	1.30E+5

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

ORNL DWG 90-8812

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 = 1.13E-1 m^3/MW(e)

TOTAL ACTIVITY = 4.07E+3 Ci/MW(e)

	GREATER THAN CLASS C
Volume, m^3/MW(e)	1.13E-1
Activity, Ci/MW(e)	4.07E+3
Specific Activity, Ci/m^3	
^{14}C	0.00E+0
^{59}Ni	1.00E+1
^{94}Nb	7.22E-2
^{99}Tc	0.00E+0
^{60}Co	1.28E+4
^{63}Ni	1.62E+3
Half-Life <5 yr	2.16E+4
Total	3.60E+4

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

ORNL DWG 88-1155

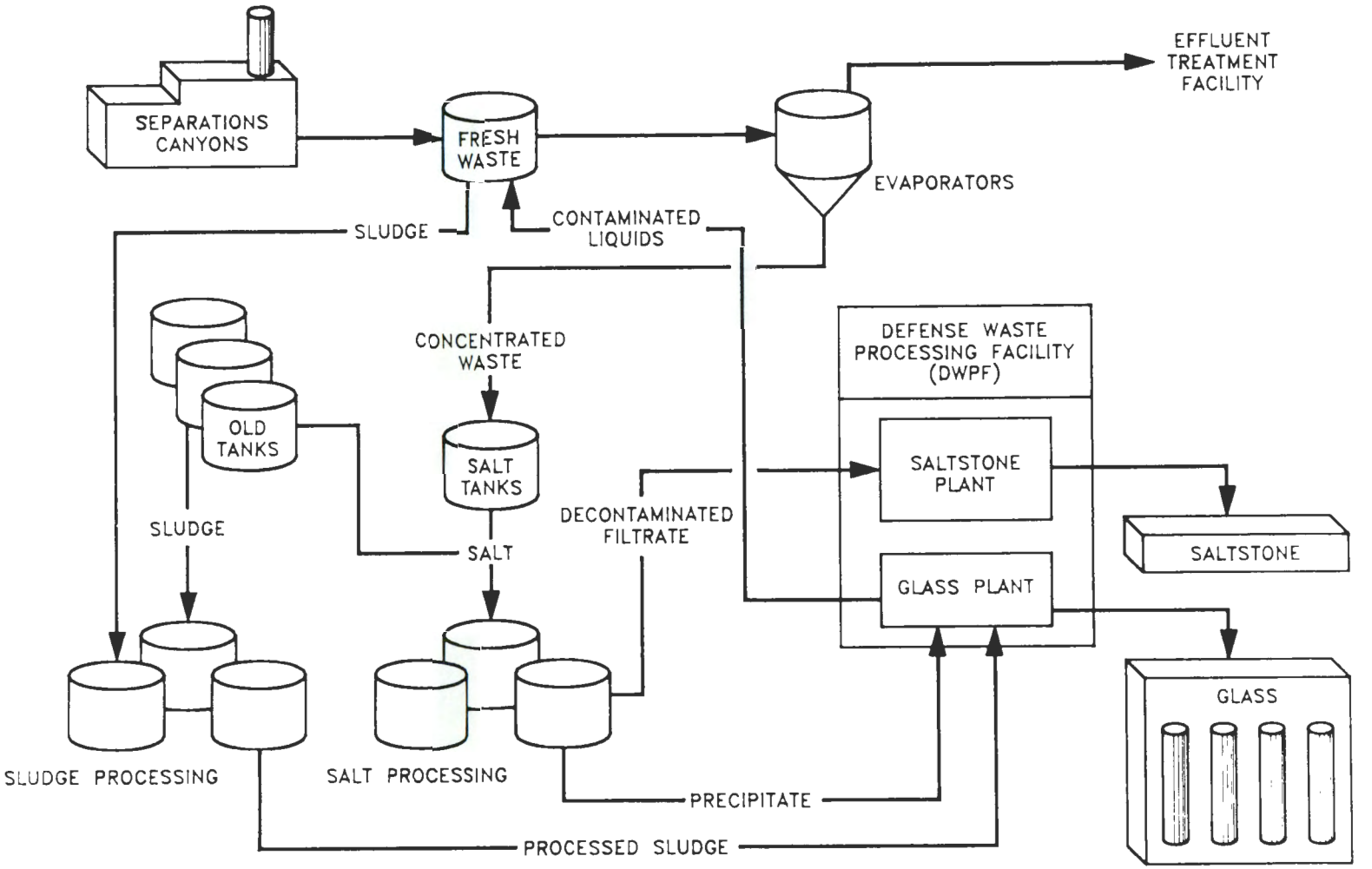


Fig. A.10. Waste flow diagram for the SRS Defense Waste Processing Facility.

Table A.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 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 medically related 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 assuming all the activity was due to ^{60}Co which would yield the greatest heat output. If the curies are 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 nuclides with half-lives <5 years, ^{3}H or ^{60}Co.

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

Facility type	Waste type	Annual waste volume generation rate
Electric power generation		Per unit energy generated [m^3/GW(e)-year]
Boiling-water reactor	LLW (routine)	547.4
	LLW (nonroutine)	19.90
Pressurized-water reactor	LLW (routine)	196.2
	LLW (nonroutine)	4.425
Nuclear fuel cycle[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 1989 (m^3/year)
	LLW	76,200
	TRU	1,398
	HLW	-4,100[e]
Industrial/institutional wastes		Annual increase in waste volume inventory during 1989 (m^3/year)
	LLW	12,400

[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 1989 (reported in Table 2.5) and the total HLW in storage through 1988 (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 A.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	1.423E+04	7.392E+04	5.101E+03	2.813E+04
B. Nonroutine wastes	5.174E+02	3.617E+05	1.151E+02	5.463E+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	4.070E+01	5.290E+06	1.130E+02	4.070E+06
Totals	3.042E+06	1.951E+09	3.122E+06	2.192E+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 A.4. Mass, radioactivity, and thermal power of nuclides in domestic commercial LWR spent fuel at the end of calendar year 1989[a]

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
1	Hydrogen	Stable[b]	9.58E+03	9.50E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Hydrogen	3	1.47E+02	1.01E+03	1.42E+06	9.79E+06	4.79E+01	3.30E+02
2	Helium	Stable	4.64E+03	4.27E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Lithium	Stable	2.18E+03	2.15E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Beryllium	Stable	1.81E+00	1.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Boron	Stable	2.00E+03	1.96E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Carbon	Stable	3.59E+05	3.53E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Carbon	14	7.70E+02	7.10E+03	3.43E+03	3.17E+04	1.01E+00	9.29E+00
7	Nitrogen	Stable	2.47E+05	2.44E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Oxygen	Stable	2.69E+08	2.65E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Fluorine	Stable	2.14E+04	2.10E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Neon	Stable	7.63E-01	7.07E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Sodium	Stable	2.99E+04	2.94E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Sodium	24	1.73E-04	1.73E-04	1.51E+03	1.51E+03	4.18E+01	4.18E+01
12	Magnesium	Stable	4.06E+03	3.99E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Aluminum	Stable	1.62E+05	1.58E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Silicon	Stable	9.58E+05	9.43E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Phosphorus	Stable	4.45E+05	4.31E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Phosphorus	32	2.91E-01	2.91E-01	8.31E+04	8.31E+04	8.42E+02	8.42E+02
16	Sulfur	Stable	5.37E+04	5.30E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Chlorine	Stable	9.92E+03	9.78E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Argon	Stable	7.33E+02	6.81E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Potassium	Stable	3.14E+00	2.92E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Calcium	Stable	3.99E+03	3.92E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Scandium	Stable	2.05E-01	1.90E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Titanium	Stable	1.65E+05	1.61E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Vanadium	Stable	3.40E+04	3.24E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Vanadium	50	1.06E+02	9.96E+02	1.90E-11	1.78E-10	2.09E-13	1.96E-12
24	Chromium	Stable	2.18E+07	2.15E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Chromium	51	7.62E+01	7.62E+01	7.05E+06	7.05E+06	1.51E+03	1.51E+03
25	Manganese	Stable	1.83E+06	1.80E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Manganese	54	1.62E+02	2.73E+02	1.25E+06	2.11E+06	6.24E+03	1.05E+04
26	Iron	Stable	6.66E+07	6.56E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iron	55	4.22E+03	1.41E+04	1.05E+07	3.54E+07	3.56E+02	1.19E+03
	Iron	59	2.84E+00	2.85E+00	1.40E+05	1.40E+05	1.08E+03	1.09E+03
27	Cobalt	Stable	1.57E+05	1.55E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cobalt	58	8.62E+01	8.85E+01	2.74E+06	2.82E+06	1.64E+04	1.69E+04
	Cobalt	60	1.17E+04	5.82E+04	1.33E+07	6.58E+07	2.05E+05	1.02E+06
28	Nickel	Stable	2.01E+07	1.97E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Nickel	59	1.08E+05	9.64E+05	8.17E+03	7.30E+04	3.25E-01	2.90E+00
	Nickel	63	1.85E+04	1.58E+05	1.14E+06	9.75E+06	1.15E+02	9.83E+02
29	Copper	Stable	3.52E+04	3.45E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Zinc	Stable	8.05E+04	7.91E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zinc	65	2.04E+01	3.01E+01	1.68E+05	2.48E+05	5.87E+02	8.67E+02
31	Gallium	Stable	6.03E+01	5.60E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Germanium	Stable	1.08E+03	9.83E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Arsenic	Stable	3.40E+02	3.10E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
34	Selenium	Stable	8.36E+04	7.58E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Selenium	79	1.00E+04	9.10E+04	6.98E+02	6.34E+03	1.74E-01	1.58E+00
35	Bromine	Stable	3.65E+04	3.32E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Krypton	Stable	5.71E+05	5.17E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Krypton	81	3.81E-02	3.44E-01	8.01E-04	7.23E-03	9.88E-08	8.92E-07
	Krypton	85	3.96E+04	2.58E+05	1.56E+07	1.01E+08	2.33E+04	1.52E+05
37	Rubidium	Stable	1.66E+05	1.50E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Rubidium	86	2.78E+00	2.78E+00	2.26E+05	2.26E+05	1.02E+03	1.02E+03
	Rubidium	87	4.13E+05	3.74E+06	3.62E-02	3.27E-01	3.02E-05	2.74E-04
38	Strontium	Stable	5.92E+05	5.36E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Strontium	89	1.02E+04	1.03E+04	2.98E+08	2.99E+08	1.03E+06	1.04E+06
	Strontium	90	8.98E+05	7.14E+06	1.23E+08	9.75E+08	1.42E+05	1.13E+06
39	Yttrium	Stable	7.21E+05	6.48E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Yttrium	90	2.28E+02	1.79E+03	1.24E+08	9.76E+08	6.87E+05	5.41E+06
	Yttrium	91	1.85E+04	1.87E+04	4.54E+08	4.59E+08	1.63E+06	1.65E+06
40	Zirconium	Stable	7.04E+08	6.99E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zirconium	93	1.41E+06	1.29E+07	3.55E+03	3.23E+04	4.12E-01	3.76E+00
	Zirconium	95	3.44E+04	3.50E+04	7.39E+08	7.52E+08	3.74E+06	3.81E+06
41	Niobium	Stable	1.01E+06	9.87E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Niobium	93m	1.04E+00	3.26E+01	2.93E+02	9.22E+03	5.19E-02	1.63E+00
	Niobium	94	1.11E+04	9.87E+04	2.08E+03	1.85E+04	2.12E+01	1.89E+02
	Niobium	95	2.93E+04	3.00E+04	1.15E+09	1.17E+09	5.50E+06	5.63E+06
	Niobium	95m	1.49E+01	1.52E+01	5.69E+06	5.78E+06	7.90E+03	8.03E+03
42	Molybdenum	Stable	6.15E+06	5.60E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Technetium	99	1.33E+06	1.21E+07	2.26E+04	2.06E+05	1.13E+01	1.03E+02
44	Ruthenium	Stable	3.70E+06	3.36E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ruthenium	103	1.34E+04	1.34E+04	4.31E+08	4.32E+08	1.44E+06	1.44E+06
	Ruthenium	106	2.17E+05	4.04E+05	7.26E+08	1.35E+09	4.32E+04	8.03E+04
45	Rhodium	Stable	7.38E+05	6.77E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Rhodium	103m	1.19E+01	1.20E+01	3.89E+08	3.89E+08	8.95E+04	8.96E+04
	Rhodium	106	2.04E-01	3.79E-01	7.26E+08	1.35E+09	6.97E+06	1.30E+07
46	Palladium	Stable	1.70E+06	1.53E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Palladium	107	3.81E+05	3.48E+06	1.96E+02	1.79E+03	1.16E-02	1.06E-01
47	Silver	Stable	1.34E+05	1.23E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Silver	108	7.02E-10	1.39E-08	5.16E-01	1.02E+01	1.92E-03	3.79E-02
	Silver	108m	2.22E-01	4.39E+00	5.80E+00	1.14E+02	5.62E-02	1.11E+00
	Silver	110	1.45E-05	2.19E-05	6.05E+04	9.14E+04	4.35E+02	6.57E+02
	Silver	110m	9.58E+02	1.45E+03	4.55E+06	6.87E+06	7.60E+04	1.15E+05
	Silver	111	2.48E+01	2.48E+01	3.91E+06	3.91E+06	8.77E+03	8.77E+03
48	Cadmium	Stable	2.32E+05	2.15E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cadmium	109	7.11E-01	1.51E+00	1.84E+03	3.91E+03	2.13E-01	4.54E-01
	Cadmium	113m	4.32E+02	3.08E+03	9.36E+04	6.68E+05	1.58E+02	1.12E+03
	Cadmium	115m	2.25E+01	2.26E+01	5.74E+05	5.76E+05	2.14E+03	2.15E+03
49	Indium	Stable	2.13E+03	2.02E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Indium	114	6.14E-05	6.17E-05	8.45E+04	8.50E+04	4.03E+02	4.05E+02
	Indium	114m	3.82E+00	3.84E+00	8.83E+04	8.88E+04	1.25E+02	1.25E+02
	Indium	115	4.48E+03	4.37E+04	2.79E-08	2.72E-07	4.00E-11	3.90E-10
	Indium	115m	4.49E-02	4.49E-02	2.85E+05	2.85E+05	5.68E+02	5.68E+02

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
50	Tin	Stable	1.15E+07	1.14E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Tin	117m	1.58E+01	1.58E+01	1.26E+06	1.26E+06	2.34E+03	2.34E+03
	Tin	119m	3.08E+03	4.48E+03	1.38E+07	2.01E+07	7.13E+03	1.04E+04
	Tin	121m	4.05E+01	3.50E+02	2.39E+03	2.07E+04	4.80E+00	4.15E+01
	Tin	123	4.16E+02	4.75E+02	3.42E+06	3.91E+06	1.07E+04	1.22E+04
	Tin	125	1.09E+01	1.09E+01	1.19E+06	1.19E+06	7.86E+03	7.86E+03
	Tin	126	4.70E+04	4.30E+05	1.33E+03	1.22E+04	1.66E+00	1.52E+01
51	Antimony	Stable	3.65E+04	3.36E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Antimony	124	3.01E+01	3.05E+01	5.26E+05	5.34E+05	6.99E+03	7.09E+03
	Antimony	125	2.67E+04	9.38E+04	2.76E+07	9.69E+07	8.63E+04	3.03E+05
	Antimony	126	1.27E+00	1.27E+00	1.06E+05	1.06E+05	1.97E+03	1.97E+03
	Antimony	127	1.12E+01	1.12E+01	3.00E+06	3.00E+06	1.78E+04	1.78E+04
52	Tellurium	Stable	7.98E+05	7.26E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Tellurium	123	1.71E+01	1.66E+02	4.96E-09	4.81E-08	5.03E-13	4.88E-12
	Tellurium	123m	1.66E+00	1.87E+00	1.47E+04	1.66E+04	2.14E+01	2.41E+01
	Tellurium	125m	3.60E+02	1.30E+03	6.48E+06	2.34E+07	5.45E+03	1.97E+04
	Tellurium	127	5.03E+00	5.41E+00	1.33E+07	1.43E+07	1.79E+04	1.93E+04
	Tellurium	127m	1.13E+03	1.23E+03	1.06E+07	1.16E+07	5.72E+03	6.26E+03
	Tellurium	129	3.63E-01	3.63E-01	7.61E+06	7.61E+06	2.72E+04	2.72E+04
	Tellurium	129m	3.73E+02	3.73E+02	1.12E+07	1.13E+07	1.97E+04	1.97E+04
	Tellurium	132	1.02E+02	1.02E+02	3.10E+07	3.10E+07	6.14E+04	6.14E+04
53	Iodine	Stable	9.22E+04	8.41E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iodine	129	3.09E+05	2.82E+06	5.46E+01	4.99E+02	2.53E-02	2.31E-01
	Iodine	131	4.51E+02	4.51E+02	5.59E+07	5.59E+07	1.90E+05	1.90E+05
54	Xenon	Stable	8.89E+06	8.07E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Xenon	129m	2.51E-03	2.51E-03	3.18E+02	3.18E+02	4.45E-01	4.45E-01
	Xenon	131m	1.81E+01	1.81E+01	1.52E+06	1.52E+06	1.46E+03	1.46E+03
	Xenon	133	4.48E+02	4.48E+02	8.38E+07	8.38E+07	8.98E+04	8.98E+04
55	Cesium	Stable	1.92E+06	1.75E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cesium	134	1.64E+05	4.78E+05	2.13E+08	6.19E+08	2.17E+06	6.30E+06
	Cesium	135	5.37E+05	4.82E+06	6.18E+02	5.55E+03	2.06E-01	1.85E+00
	Cesium	136	5.65E+01	5.65E+01	4.14E+06	4.14E+06	5.65E+04	5.65E+04
	Cesium	137	2.03E+06	1.62E+07	1.76E+08	1.41E+09	1.95E+05	1.56E+06
56	Barium	Stable	2.31E+06	2.09E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Barium	136m	2.53E-06	2.53E-06	6.83E+05	6.83E+05	8.25E+03	8.25E+03
	Barium	137m	3.10E-01	2.48E+00	1.67E+08	1.34E+09	6.55E+05	5.25E+06
	Barium	140	2.02E+03	2.02E+03	1.47E+08	1.47E+08	4.11E+05	4.11E+05
57	Lanthanum	Stable	2.08E+06	1.89E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Lanthanum	138	9.74E+00	8.92E+01	1.87E-07	1.71E-06	1.37E-09	1.26E-08
	Lanthanum	140	3.06E+02	3.06E+02	1.70E+08	1.70E+08	2.85E+06	2.85E+06
58	Cerium	Stable	2.06E+06	1.87E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cerium	141	1.25E+04	1.25E+04	3.57E+08	3.57E+08	5.22E+05	5.23E+05
	Cerium	142	1.92E+06	1.74E+07	4.62E-02	4.19E-01	0.00E+00	0.00E+00
	Cerium	144	4.49E+05	7.17E+05	1.43E+09	2.29E+09	9.51E+05	1.52E+06
59	Praseodymium	Stable	1.84E+06	1.66E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Praseodymium	143	2.20E+03	2.20E+03	1.48E+08	1.48E+08	2.76E+05	2.76E+05
	Praseodymium	144	1.90E+01	3.03E+01	1.43E+09	2.29E+09	1.05E+07	1.68E+07
	Praseodymium	144m	9.48E-02	1.51E-01	1.72E+07	2.75E+07	5.89E+03	9.40E+03

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
60	Neodymium	Stable	4.58E+06	4.17E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Neodymium	144	1.78E+06	1.93E+07	2.10E-06	2.28E-05	0.00E+00	0.00E+00
	Neodymium	147	6.02E+02	6.02E+02	4.84E+07	4.84E+07	1.17E+05	1.17E+05
61	Promethium	147	2.36E+05	8.00E+05	2.19E+08	7.42E+08	7.85E+04	2.66E+05
	Promethium	148	6.16E+01	6.16E+01	1.01E+07	1.01E+07	7.79E+04	7.79E+04
	Promethium	148m	3.91E+02	3.92E+02	8.35E+06	8.37E+06	1.06E+05	1.06E+05
62	Samarium	Stable	7.44E+05	6.82E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Samarium	147	1.29E+05	2.62E+06	2.93E-03	5.95E-02	4.01E-05	8.14E-04
	Samarium	148	2.77E+05	2.45E+06	8.37E-08	7.40E-07	1.00E-09	8.83E-09
	Samarium	149	5.50E+03	5.38E+04	1.32E-09	1.29E-08	0.00E+00	0.00E+00
	Samarium	151	2.39E+04	2.16E+05	6.28E+05	5.68E+06	7.36E+01	6.66E+02
63	Europium	Stable	1.84E+05	1.65E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Europium	152	5.76E+01	4.09E+02	9.96E+03	7.08E+04	7.53E+01	5.36E+02
	Europium	154	6.25E+04	3.76E+05	1.69E+07	1.01E+08	1.51E+05	9.08E+05
	Europium	155	2.21E+04	1.07E+05	1.03E+07	4.97E+07	7.49E+03	3.62E+04
	Europium	156	3.63E+02	3.63E+02	2.00E+07	2.00E+07	2.07E+05	2.07E+05
64	Gadolinium	Stable	1.29E+06	1.29E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Gadolinium	152	1.70E+02	2.10E+03	3.69E-09	4.58E-08	4.81E-11	5.96E-10
	Gadolinium	153	3.26E+02	4.53E+02	1.15E+06	1.60E+06	1.04E+03	1.44E+03
65	Terbium	Stable	1.90E+04	1.82E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Terbium	160	1.57E+02	1.61E+02	1.77E+06	1.82E+06	1.44E+04	1.48E+04
	Terbium	161	1.40E+00	1.40E+00	1.64E+05	1.64E+05	3.29E+02	3.29E+02
81	Thallium	Stable	1.58E-09	1.41E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Thallium	206	5.80E-22	5.80E-22	1.26E-13	1.26E-13	1.14E-15	1.14E-15
	Thallium	207	3.89E-12	2.14E-10	7.42E-04	4.07E-02	2.18E-06	1.20E-04
	Thallium	208	5.69E-09	2.65E-07	1.68E+00	7.81E+01	3.95E-02	1.84E+00
	Thallium	209	9.84E-15	7.43E-14	4.02E-06	3.04E-05	6.69E-08	5.05E-07
82	Lead	Stable	1.97E+03	1.94E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Lead	204	2.75E+01	2.70E+02	3.44E-13	3.38E-12	5.30E-15	5.21E-14
	Lead	205	5.89E-02	5.47E-01	3.43E-06	3.18E-05	9.96E-11	9.24E-10
	Lead	209	1.65E-10	4.34E-10	7.51E-04	1.97E-03	8.64E-07	2.27E-06
	Lead	210	5.33E-08	6.32E-06	4.07E-06	4.83E-04	9.44E-10	1.12E-07
	Lead	211	3.01E-11	1.65E-09	7.44E-04	4.09E-02	2.23E-06	1.22E-04
	Lead	212	3.36E-06	1.56E-04	4.67E+00	2.17E+02	8.88E-03	4.14E-01
	Lead	214	1.03E-12	1.17E-10	3.37E-05	3.83E-03	1.08E-07	1.22E-05
83	Bismuth	Stable	7.99E+02	7.85E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Bismuth	208	9.46E-03	8.74E-02	4.42E-05	4.08E-04	6.95E-07	6.43E-06
	Bismuth	210	1.36E-05	1.36E-05	1.69E+00	1.69E+00	3.89E-03	3.89E-03
	Bismuth	210m	5.60E-02	5.20E-01	3.18E-05	2.95E-04	9.98E-07	9.27E-06
	Bismuth	211	1.78E-12	9.76E-11	7.44E-04	4.09E-02	2.97E-05	1.63E-03
	Bismuth	212	3.18E-07	1.48E-05	4.67E+00	2.17E+02	7.93E-02	3.69E+00
	Bismuth	213	9.63E-12	7.28E-11	1.86E-04	1.41E-03	7.83E-07	5.92E-06
	Bismuth	214	7.63E-13	8.68E-11	3.37E-05	3.83E-03	4.32E-07	4.91E-05
84	Polonium	210	8.63E-03	1.01E-02	3.88E+01	4.53E+01	1.24E+00	1.45E+00
	Polonium	211	2.18E-17	1.20E-15	2.08E-06	1.14E-04	9.37E-08	5.15E-06
	Polonium	212	1.68E-17	7.84E-16	2.99E+00	1.39E+02	1.58E-01	7.38E+00
	Polonium	213	1.44E-20	1.09E-19	1.82E-04	1.38E-03	9.22E-06	6.97E-05
	Polonium	214	1.37E-19	1.20E-17	4.41E-05	3.84E-03	2.05E-06	1.79E-04

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
	Polonium	215	2.52E-17	1.39E-15	7.44E-04	4.09E-02	3.32E-05	1.82E-03
	Polonium	216	1.34E-11	6.23E-10	4.66E+00	2.17E+02	1.91E-01	8.89E+00
	Polonium	218	1.19E-13	1.36E-11	3.37E-05	3.84E-03	1.22E-06	1.39E-04
85	Astatine	217	1.16E-16	8.74E-16	1.86E-04	1.41E-03	7.95E-06	6.01E-05
86	Radon	218	7.02E-18	7.02E-18	1.04E-05	1.04E-05	4.47E-07	4.47E-07
	Radon	219	5.71E-14	3.14E-12	7.44E-04	4.09E-02	3.09E-05	1.70E-03
	Radon	220	5.05E-09	2.35E-07	4.66E+00	2.17E+02	1.77E-01	8.25E+00
	Radon	222	2.19E-10	2.49E-08	3.37E-05	3.84E-03	1.12E-06	1.27E-04
87	Francium	221	1.05E-12	7.94E-12	1.86E-04	1.41E-03	7.19E-06	5.43E-05
	Francium	223	2.90E-13	1.48E-11	1.12E-05	5.74E-04	2.91E-08	1.49E-06
88	Radium	222	7.76E-15	7.76E-15	1.04E-05	1.04E-05	4.11E-07	4.11E-07
	Radium	223	1.45E-08	7.97E-07	7.44E-04	4.09E-02	2.65E-05	1.45E-03
	Radium	224	2.92E-05	1.36E-03	4.66E+00	2.17E+02	1.60E-01	7.45E+00
	Radium	225	4.33E-09	3.55E-08	1.70E-04	1.39E-03	1.19E-07	9.77E-07
	Radium	226	3.44E-05	3.89E-03	3.40E-05	3.85E-03	9.83E-07	1.11E-04
	Radium	228	1.86E-11	2.30E-09	4.35E-09	5.38E-07	3.35E-13	4.15E-11
89	Actinium	225	3.21E-09	2.42E-08	1.86E-04	1.41E-03	6.51E-06	4.92E-05
	Actinium	227	1.12E-05	5.75E-04	8.13E-04	4.16E-02	3.94E-07	2.01E-05
	Actinium	228	3.16E-12	3.39E-12	7.08E-06	7.61E-06	6.12E-08	6.58E-08
90	Thorium	226	3.87E-13	3.87E-13	1.04E-05	1.04E-05	3.97E-07	3.97E-07
	Thorium	227	2.47E-08	1.32E-06	7.58E-04	4.06E-02	2.77E-05	1.48E-03
	Thorium	228	5.61E-03	2.63E-01	4.60E+00	2.16E+02	1.50E-01	7.06E+00
	Thorium	229	6.84E-04	6.44E-03	1.46E-04	1.37E-03	4.45E-06	4.19E-05
	Thorium	230	2.48E+00	7.89E+01	5.01E-02	1.59E+00	1.42E-03	4.51E-02
	Thorium	231	7.52E-05	6.94E-04	4.00E+01	3.69E+02	2.25E-02	2.07E-01
	Thorium	232	3.75E-01	1.34E+01	4.11E-08	1.47E-06	9.95E-10	3.57E-08
	Thorium	233	7.28E-12	7.28E-12	2.66E-04	2.66E-04	6.73E-07	6.73E-07
	Thorium	234	2.76E-02	2.72E-01	6.39E+02	6.29E+03	2.59E-01	2.55E+00
91	Protactinium	231	4.45E-01	5.00E+00	2.10E-02	2.36E-01	6.33E-04	7.12E-03
	Protactinium	232	8.08E-06	8.08E-06	3.47E+00	3.47E+00	2.27E-02	2.27E-02
	Protactinium	233	2.45E-02	2.18E-01	5.08E+02	4.52E+03	1.15E+00	1.03E+01
	Protactinium	234	4.19E-07	4.09E-06	8.38E-01	8.19E+00	1.20E-02	1.18E-01
	Protactinium	234m	9.29E-07	9.16E-06	6.39E+02	6.29E+03	3.16E+00	3.11E+01
	Protactinium	235	7.55E-17	7.55E-17	2.51E-09	2.51E-09	7.00E-12	7.00E-12
92	Uranium	230	3.80E-10	3.80E-10	1.04E-05	1.04E-05	3.68E-07	3.68E-07
	Uranium	231	3.43E-09	3.43E-09	4.61E-04	4.61E-04	3.81E-07	3.81E-07
	Uranium	232	7.96E-01	1.38E+01	1.70E+01	2.96E+02	5.47E-01	9.50E+00
	Uranium	233	2.30E+00	3.21E+01	2.23E-02	3.11E-01	6.48E-04	9.03E-03
	Uranium	234	3.31E+05	3.27E+06	2.07E+03	2.04E+04	5.96E+01	5.89E+02
	Uranium	235	1.63E+07	1.68E+08	3.53E+01	3.64E+02	9.25E-01	9.54E+00
	Uranium	236	6.70E+06	6.07E+07	4.34E+02	3.93E+03	1.18E+01	1.06E+02
	Uranium	237	4.47E+02	4.47E+02	3.65E+07	3.65E+07	6.91E+04	6.91E+04
	Uranium	238	1.90E+09	1.87E+10	6.39E+02	6.29E+03	1.62E+01	1.60E+02
	Uranium	239	1.76E-02	1.76E-02	5.90E+05	5.90E+05	1.59E+03	1.59E+03
	Uranium	240	2.28E-04	2.28E-04	2.11E+02	2.11E+02	1.73E-01	1.73E-01
93	Neptunium	235	4.89E-03	9.53E-03	6.87E+00	1.34E+01	3.99E-04	7.77E-04
	Neptunium	236	6.14E-01	5.31E+00	8.09E-03	7.00E-02	1.63E-05	1.41E-04
	Neptunium	236m	7.40E-05	7.40E-05	4.37E+01	4.37E+01	3.45E-02	3.45E-02

Table A.4 (continued)

Atomic number	Element	Mass number of nuclide	Mass, g		Radioactivity, Ci		Thermal power, W	
			Annual rate	Accumulation	Annual rate	Accumulation	Annual rate	Accumulation
	Neptunium	237	7.19E+05	6.41E+06	5.07E+02	4.52E+03	1.55E+01	1.38E+02
	Neptunium	238	1.68E+01	1.68E+01	4.37E+06	4.37E+06	2.09E+04	2.09E+04
	Neptunium	239	1.51E+03	1.51E+03	3.49E+08	3.50E+08	8.45E+05	8.45E+05
	Neptunium	240	3.67E-04	3.67E-04	4.43E+03	4.43E+03	4.69E+01	4.69E+01
	Neptunium	240m	2.03E-06	2.03E-06	2.15E+02	2.15E+02	1.25E+00	1.25E+00
	Neptunium	241	1.42E-13	1.42E-13	6.91E-06	6.91E-06	1.93E-08	1.93E-08
94	Plutonium	236	1.55E+00	5.50E+00	8.24E+02	2.92E+03	2.87E+01	1.02E+02
	Plutonium	237	1.41E-02	1.42E-02	1.70E+02	1.71E+02	6.28E-02	6.31E-02
	Plutonium	238	2.15E+05	1.86E+06	3.68E+06	3.19E+07	1.22E+05	1.06E+06
	Plutonium	239	9.72E+06	9.39E+07	6.04E+05	5.84E+06	1.86E+04	1.80E+05
	Plutonium	240	4.07E+06	3.77E+07	9.27E+05	8.59E+06	2.89E+04	2.67E+05
	Plutonium	241	2.22E+06	1.59E+07	2.29E+08	1.64E+09	7.09E+03	5.10E+04
	Plutonium	242	7.87E+05	7.09E+06	3.00E+03	2.71E+04	8.87E+01	8.00E+02
	Plutonium	243	1.57E-01	1.57E-01	4.09E+05	4.09E+05	4.72E+02	4.72E+02
	Plutonium	244	3.92E+01	3.59E+02	6.95E-04	6.38E-03	2.02E-05	1.85E-04
	Plutonium	245	1.46E-06	1.46E-06	1.76E+00	1.76E+00	4.17E-03	4.17E-03
	Plutonium	246	3.08E-07	3.08E-07	1.51E-02	1.51E-02	1.27E-05	1.27E-05
95	Americium	239	2.96E-09	2.96E-09	3.27E-03	3.27E-03	7.89E-06	7.89E-06
	Americium	240	1.29E-05	1.29E-05	3.31E+00	3.31E+00	2.16E-02	2.16E-02
	Americium	241	1.09E+05	5.63E+06	3.75E+05	1.93E+07	1.24E+04	6.42E+05
	Americium	242	4.36E-01	5.44E-01	3.53E+05	4.40E+05	4.00E+02	4.99E+02
	Americium	242m	1.17E+03	1.02E+04	1.14E+04	9.92E+04	4.50E+00	3.92E+01
	Americium	243	1.46E+05	1.31E+06	2.92E+04	2.62E+05	9.37E+02	8.41E+03
	Americium	244	1.03E-02	1.03E-02	1.31E+04	1.31E+04	6.87E+01	6.87E+01
	Americium	244m	1.06E-04	1.06E-04	3.14E+03	3.14E+03	9.50E+00	9.50E+00
	Americium	245	3.43E-07	3.43E-07	2.12E+00	2.12E+00	3.93E-03	3.93E-03
	Americium	246	4.93E-10	4.93E-10	1.51E-02	1.51E-02	1.22E-04	1.22E-04
96	Curium	242	1.05E+04	1.31E+04	3.48E+07	4.35E+07	1.28E+06	1.60E+06
	Curium	243	5.49E+02	4.29E+03	2.84E+04	2.22E+05	1.04E+03	8.13E+03
	Curium	244	3.99E+04	3.01E+05	3.23E+06	2.43E+07	1.13E+05	8.51E+05
	Curium	245	1.46E+03	1.34E+04	2.50E+02	2.30E+03	8.31E+00	7.64E+01
	Curium	246	1.77E+02	1.68E+03	5.43E+01	5.16E+02	1.78E+00	1.69E+01
	Curium	247	1.62E+00	1.59E+01	1.50E-04	1.48E-03	4.79E-06	4.73E-05
	Curium	248	8.14E-02	8.40E-01	3.46E-04	3.57E-03	4.31E-05	4.45E-04
	Total		3.09E+09	3.05E+10	1.08E+10	2.07E+10	4.41E+07	7.83E+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 A.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						
^{234}Pa	0.0034	^{144}Ce	14.67						100.00
^{235}U	0.0258	^{144}Pr	14.67						
^{238}U	33.197	^{147}Pm	0.06						
		^{151}Sm	0.11						
	100.0000	^{152}Eu	0.09						
		^{154}Eu	0.09						
		^{155}Eu	0.06						
			100.00						

[a]Based on ref. 1.

Table A.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	5.897E-02
^{14}C	5.730E+03 y	2.900E-03
^{51}Cr	2.770E+01 d	8.659E-02
^{54}Mn	3.127E+02 d	9.932E-01
^{58}Co	7.080E+01 d	1.271E+00
^{59}Fe	4.463E+01 d	8.571E-03
^{60}Co	5.271E+00 y	8.872E-01
^{65}Zn	2.444E+02 d	3.323E-03
^{90}Sr	2.860E+01 y	4.432E-01
^{90}Y	6.110E+01 h	4.432E-01
^{95}Zr	6.402E+01 d	5.446E-03
^{95}Nb	3.506E+01 d	1.214E-02
^{99}Tc	2.130E+05 y	5.887E-03
^{125}Sb	2.770E+00 y	1.257E-02
^{125m}Te	5.800E+01 d	3.131E-03
^{106}Ru	3.682E+02 d	2.740E-02
^{106}Rh	2.992E+02 s	2.740E-02
^{134}Cs	2.062E+00 y	6.773E-01
^{137}Cs	3.017E+01 y	1.000E+00
^{137m}Ba	2.552E+00 min	9.460E-01
^{144}Ce	2.843E+02 d	6.291E-02
^{144}Pr	1.728E+01 min	6.291E-02
^{147}Pm	2.623E+00 y	2.573E-04
^{151}Sm	9.000E+01 y	4.717E-04
^{152}Eu	1.360E+01 y	3.860E-04
^{154}Eu	8.800E+00 y	3.860E-04
^{155}Eu	4.960E+00 y	2.573E-04
^{226}Ra	1.600E+03 y	1.156E-04
^{232}Th	1.405E+10 y	1.569E-05
^{235}U	7.038E+08 y	1.817E-06
^{238}U	4.468E+09 y	2.337E-03
^{238}Pu	8.775E+01 y	7.094E-01[c]
^{239}Pu	2.413E+04 y	1.915E-03[c]
^{241}Am	4.322E+02 y	3.603E-04
Total		7.757E+00

[a]Taken from ref. 1.

[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.

Table A.7. 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
1991	0.023	0.112	0.112	0.201	0.000	0.000	0.007	0.029	0.027	0.489	1.00
1992	0.020	0.087	0.087	0.259	0.001	0.001	0.016	0.023	0.021	0.487	1.00
1993	0.020	0.088	0.088	0.254	0.001	0.001	0.011	0.022	0.021	0.494	1.00
1994	0.022	0.095	0.095	0.262	0.000	0.000	0.009	0.024	0.022	0.468	1.00
1995	0.025	0.102	0.102	0.286	0.000	0.000	0.008	0.027	0.025	0.424	1.00
1996	0.030	0.109	0.109	0.303	0.000	0.000	0.007	0.028	0.026	0.386	1.00
1997	0.030	0.109	0.109	0.352	0.000	0.000	0.006	0.028	0.026	0.339	1.00
1998	0.033	0.115	0.115	0.365	0.000	0.000	0.006	0.028	0.025	0.313	1.00
1999	0.036	0.123	0.123	0.379	0.000	0.000	0.005	0.027	0.025	0.280	1.00
2000	0.039	0.132	0.132	0.394	0.000	0.000	0.005	0.027	0.025	0.245	1.00
2001	0.042	0.141	0.141	0.409	0.000	0.000	0.004	0.027	0.025	0.211	1.00
2002	0.044	0.150	0.150	0.422	0.000	0.000	0.004	0.027	0.025	0.178	1.00
2003	0.046	0.158	0.158	0.433	0.000	0.000	0.004	0.027	0.024	0.149	1.00
2004	0.048	0.165	0.165	0.442	0.000	0.000	0.004	0.026	0.024	0.124	1.00
2005	0.050	0.172	0.172	0.449	0.000	0.000	0.003	0.026	0.024	0.103	1.00
2006	0.050	0.178	0.178	0.456	0.000	0.000	0.003	0.026	0.024	0.085	1.00
2007	0.050	0.178	0.178	0.467	0.000	0.000	0.003	0.026	0.024	0.073	1.00
2008	0.051	0.178	0.178	0.477	0.000	0.000	0.003	0.026	0.024	0.063	1.00
2009	0.051	0.177	0.177	0.487	0.000	0.000	0.003	0.026	0.023	0.054	1.00
2010	0.052	0.176	0.176	0.496	0.000	0.000	0.003	0.025	0.023	0.047	1.00
2011	0.053	0.175	0.175	0.504	0.000	0.000	0.003	0.025	0.023	0.041	1.00
2012	0.054	0.176	0.176	0.508	0.000	0.000	0.003	0.025	0.023	0.035	1.00
2013	0.054	0.176	0.176	0.512	0.000	0.000	0.003	0.025	0.023	0.030	1.00
2014	0.055	0.176	0.176	0.516	0.000	0.000	0.003	0.024	0.022	0.026	1.00
2015	0.055	0.176	0.176	0.520	0.000	0.000	0.003	0.024	0.022	0.023	1.00
2016	0.056	0.176	0.176	0.523	0.000	0.000	0.003	0.024	0.022	0.020	1.00
2017	0.056	0.176	0.176	0.526	0.000	0.000	0.002	0.023	0.021	0.018	1.00
2018	0.057	0.176	0.176	0.529	0.000	0.000	0.002	0.023	0.021	0.016	1.00
2019	0.057	0.175	0.175	0.532	0.000	0.000	0.002	0.022	0.021	0.014	1.00
2020	0.057	0.175	0.175	0.535	0.000	0.000	0.002	0.022	0.020	0.013	1.00

[a]Taken from ref. 3.

[b]Chemical composition (wt %): flyash, 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 A.8. Historical and projected commercial LWR net annual electrical generation for the DOE/EIA No New Orders Case[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	1990	18,901	42,899	61,800
1961	60	97	157	1991	19,048	43,812	62,860
1962	137	96	233	1992	18,962	44,851	63,813
1963	136	208	344	1993	19,081	45,488	64,569
1964	164	198	362	1994	18,995	45,522	64,517
1965	164	212	376	1995	19,064	46,297	65,361
1966	221	334	556	1996	19,115	46,541	65,656
1967	184	419	603	1997	19,167	46,799	65,966
1968	205	781	986	1998	19,322	47,198	66,520
1969	238	1,049	1,287	1999	19,287	47,119	66,406
1970	1,011	1,192	2,203	2000	19,339	47,532	66,871
1971	1,969	2,103	4,075	2001	19,424	47,968	67,392
1972	3,188	2,450	5,641	2002	19,510	48,093	67,603
1973	4,446	4,620	9,073	2003	19,562	48,431	67,993
1974	5,298	6,650	11,955	2004	19,639	48,634	68,273
1975	6,309	12,089	17,395	2005	19,725	48,836	68,561
1976	8,044	13,113	21,343	2006	19,810	49,038	68,848
1977	9,636	17,737	27,388	2007	19,896	48,851	68,747
1978	11,353	19,596	31,142	2008	19,982	48,795	68,777
1979	11,390	17,332	28,662	2009	19,774	49,252	69,026
1980	10,416	17,848	28,343	2010	19,011	49,602	68,613
1981	10,187	20,310	30,517	2011	17,250	47,531	64,781
1982	10,201	20,716	30,938	2012	16,005	46,144	62,149
1983	9,363	22,494	31,883	2013	14,827	41,304	56,131
1984	9,766	26,427	35,072	2014	11,321	37,223	48,544
1985	12,151	30,413	41,382	2015	11,302	35,371	46,673
1986	12,737	33,726	46,495	2016	10,332	32,203	42,535
1987	14,810	36,465	51,275	2017	10,323	30,029	40,352
1988	16,722	41,639	58,361	2018	9,837	29,437	39,274
1989	16,845	43,489	60,334	2019	9,774	29,231	39,005
				2020	9,768	26,767	36,535

[a]Data for 1960–1989 are based on refs. 7 and 9.
[b]Data for 1990–2020 are based on ref. 10.

Table A.9. Waste core components and structurals[a] from BWRs and PWRs reported as shipped off-site for disposal as of December 31, 1989[b]

Boiling-water reactor	Irradiated core component shipments: Total volume (m^3)	Total radioactivity (Ci)	Dates shipped	Pressurized-water reactor	Irradiated core component shipments: Total volume (m^3)	Total radioactivity (Ci)	Dates shipped
Dresden 1,2,&3	126.7	290,751	1961, 1962, 1965, 1968, 1969, 1971, 1973, 1974, 1982, 1985, 1986, 1988, and 1989	Yankee Rowe	108.0 (+ 11 casks)	208,461	1963, 1964, 1965, 1966, 1967, 1968, 1969, 1973, 1976, 1981, and 1988
Big Rock Point	47.4	55,723	1966, 1967, 1970, 1972, 1973, 1981, 1987, and 1988	San Onofre 1	1.7	7	1968 and 1985
Humboldt Bay	5.3	18,483	1964, 1968, and 1983	Haddam	18.5	39	1977
La Crosse	0.8	16,836	1977	Palisades	14.1	54,709.8	1974, 1976, 1978, 1979, 1981, 1983, 1988, and 1989
Oyster Creek	78.3	451,423	1977, 1982, 1984, 1987, 1988, and 1989	Maine Yankee	7.9	35,330	1976, 1977, 1978, and 1979
Nine Mile Point	137.8	143,597	1977, 1978, 1980, 1982, 1983, 1984, 1985, and 1986	Kewaunee	106.1	14.2	1976 and 1979
Millstone 1	54.1	193,512.7	1978, 1979, 1988, and 1989	Rancho Seco	2.4	19.1	1976, 1977, and 1986
Monticello	46.4	239,150	1977, 1978, 1979, 1982, 1983, 1985, 1986, and 1989	Calvert Cliffs 1&2	732.0	67,483	1977, 1978, 1979, 1980, 1981, 1982, 1984, and 1985
Vermont Yankee	181.3	219,377[c]	1977, 1978, 1983, 1985, 1986, and 1987	St. Lucie 1&2	173.4	182,991	1976, 1977, 1978, 1983, 1984, and 1988
Pilgrim	1,883.4	169,934	1976, 1977, 1978, 1979, and 1985	Crystal River	10.3	30,299	1978, 1983, 1984, and 1985
Browns Ferry 1,2,&3	887.3	9,927.4	1977, 1979, and 1980	Indian Point 1&2	19.4	27.3	1978 and 1985
Cooper	31.3	33,163	1977, 1979, 1985, and 1986	Millstone 2	20.9	128,969	1979, 1980, 1984, and 1987
Hatch 1&2	158.4	48,632	1975, 1976, 1977, 1978, 1979, 1982, 1984, 1985, and 1987	Oconee 1,2,&3	311.7	17,033.3	1980, 1984, 1985, and 1989

Table A.9 (continued)

Boiling-water reactor	Irradiated core component shipments: Total volume (m^3)	Total radioactivity (Ci)	Dates shipped	Pressurized-water reactor	Irradiated core component shipments: Total volume (m^3)	Total radioactivity (Ci)	Dates shipped
FitzPatrick	25.5	45,910.5	1977, 1978, 1988, and 1989	Farley 1&2	1.0	5.1	1983
Brunswick 1&2	43.7	51,860	1975, 1976, 1977, 1978, 1983, 1986, 1987, and 1989	North Anna 1&2	38.8	961	1983
				Arkansas Nuclear One 1&2	402.2	1,090	1982 and 1984
Peach Bottom 2&3	26.4	223,619	1984, 1985, 1986, and 1989	Fort Calhoun	186	29.5	1976
Quad Cities 1&2	55.7	252,238	1984, 1985, 1987, and 1989	Prairie Island	0.4	15	1976
Grand Gulf	0.4	42	1987	Cook 1&2	8.6	1,130	1985
Duane Arnold	1.6	15,900	1989	Robinson-2	1.6	3,100	1985
Limerick 1&2	0.6	31,400	1989	Zion 1&2	6.8	1,998.7	1985
				Sequoyah 1&2	3.3	11,200	1986
				Slurry 1&2	6.5	28,800	1987
				Indian Point 3	2.2	74.8	1987
				Waterford	0.7	3,850	1988
				Salem 1&2	1.1	55,400	1989
Total	3,750.6	2,511,478	1959-1989	Total	2,185.5	833,036.5	1960-1989

[a]Includes curtains, shrouds, control rods, control rod blades, control rod channels, fuel channels, in-core chambers, flux wires, source pins, support tubes, thermal shield and hold-down device, control rod drive index tubes, in-core wire, dummy fuel rods, orifices, stiffeners, channel plugs, channel pieces, transition pieces, etc.

[b]Based on information extracted from refs. 7 and 8.

[c]Exponential error in semiannual report (January-June 1987) corrected.

Table A.10. Projected number and volume of drums and classes of LLW incorporated in cement to be generated in the WVDP 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	-	g	5,068	1,368
1991[h]	-	g	1,900	513
Total number	726	g	13,500	
Total volume, m^3	196	g	3,644	3,840

[a]The so-called square drums used are parallelopipeds of square cross section (~0.6 m × 0.6 m × 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. 11.

[d]Alkaline HLW liquid is being decontaminated to LLW in the WVDP Supernatant Treatment System (see Sect. 2.2.4). This LLW effluent is being solidified with cement in the Cement Solidification System.

[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]Cement solidification of the decontaminated liquid only is expected to be completed in April 1991.

Table A.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 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 1988 – Viability Assessment, DOE/EIA-0477(88), Washington, D.C. (December 1989).

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]

Radionuclide	Atomic number	Half-life[b]	Specific activity (Ci/g)	"Q" value[c] (MeV/dis)	"Q" value[c] (W/Ci)	Principal mode(s) of decay[d]	Daughter(s)
^{3}H	1	1.233E+01 y	9.650E+03	5.68E-03	3.37E-05	β	^{3}He
^{14}C	6	5.730E+03 y	4.457	4.95E-02	2.93E-04	β	^{14}N
^{32}P	15	14.282 d	2.853E+05	6.95E-01	4.12E-03	β	^{32}S
^{35}S	16	87.51 d	4.263E+04	4.86E-02	2.88E-04	β	^{35}Cl
^{36}Cl	17	3.01E+05 y	3.299E-02	2.460E-01	1.458E-03	β (98.1%); EC (1.9%)	^{36}Ar; ^{36}S
^{45}Ca	20	163.8 d	1.780E+04	7.70E-02	4.56E-04	β	^{45}Sc
^{46}Sc	21	83.83 d	3.381E+04	2.121	1.257E-02	β	^{46}Ti
^{51}Cr	24	27.704 d	9.240E+04	3.56E-02	2.11E-04	EC	^{51}V
^{54}Mn	25	312.20 d	7.738E+03	8.394E-01	4.975E-03	EC	^{54}Cr
^{55}Fe	26	2.73 y	2.500E+03	5.4E-03	3.2E-05	EC	^{55}Mn
^{59}Fe	26	44.496 d	4.918E+04	1.306	7.741E-03	β	^{59}Co
^{57}Co	27	271.77 d	8.456E+03	1.428E-01	8.464E-01	EC	^{57}Fe
^{58}Co	27	70.92 d	3.181E+04	1.01	5.99E-03	EC	^{58}Fe
^{60}Co	27	5.271 y	1.131E+03	2.600	1.541E-02	β	^{60}Ni
^{60m}Co	27	10.47 min	2.993E+08	6.02E-02	3.57E-04	IT (99.75%); β (0.25%)	^{60}Co; ^{60}Ni
^{59}Ni	28	7.5E+04 y	7.574E+04	6.72E-03	3.98E-05	EC	^{59}Co
^{63}Ni	28	1.001E+02 y	6.168E+01	1.71E-02	1.01E-04	β	^{63}Cu
^{65}Zn	30	244.1 d	8.237E+03	5.91E-01	3.51E-03	EC	^{65}Cu
^{67}Ga	31	3.261 d	5.975E+05	1.881E-01	1.115E-03	EC	^{67}Zn
^{75}Se	34	119.77 d	1.453E+04	4.06E-01	2.41E-03	EC	^{75}As
^{79}Se	34	<6.5E+04 y	6.966E-02	5.29E-02	3.13E-04	β	^{79}Br
^{85}Kr	36	1.072E+01 y	3.923E+02	2.53E-01	1.50E-03	β	^{85}Rb
^{86}Rb	37	18.66 d	8.138E+04	7.62E-01	4.52E-03	β	^{86}Sr
^{89}Sr	38	50.55 d	2.905E+04	5.83E-01	3.46E-03	β	^{89}Y
^{90}Sr	38	2.85E+01 y	1.364E+02	1.96E-01	1.16E-03	β	^{90}Y
^{90}Y	39	2.671 d	5.441E+05	9.34E-01	5.54E-03	β	^{90}Zr
^{91}Y	39	58.51 d	2.452E+04	6.07E-01	3.60E-03	β	^{91}Zr

Table B.1 (continued)

Radionuclide	Atomic number	Half-life[b]	Specific activity (Ci/g)	"Q" value[c] (MeV/dis)	"Q" value[c] (W/Ci)	Principal mode(s) of decay[d]	Daughter(s)
^{93}Zr	40	1.53E+06 y	2.513E-03	4.89E-02	2.90E-04	β	^{93}Nb
^{95}Zr	40	64.02 d	2.148E+04	8.53E-01	5.06E-03	β	^{95}Nb
^{93m}Nb	41	1.36E+01 y	2.826E+02	2.99E-02	1.77E-04	IT	^{93}Nb
^{94}Nb	41	2.03E+04 y	1.873E-01	1.718	1.018E-02	β	^{94}Mo
^{95}Nb	41	34.97 d	3.910E+04	8.078E-01	4.788E-03	β	^{95}Mo
^{99}Mo	42	2.748 d	4.796E+05	6.796E-01	4.028E-03	β	^{99}Tc
^{99}Tc	43	2.13E+05 y	1.695E-02	8.5E-02	5.0E-04	β	^{99}Ru
^{99m}Tc	43	6.006 h	5.271E+06	1.381E-01	8.186E-04	IT	^{99}Tc
^{103}Ru	44	39.254 d	3.227E+04	5.95E-01	3.53E-03	β	^{103}Rh
^{106}Ru	44	1.020 y	3.346E+03	1.004E-01	5.951E-04	β	^{106}Rh
^{103m}Rh	45	56.12 min	3.253E+07	3.92E-02	2.32E-04	IT	^{103}Rh
^{106}Rh	45	2.17 h	3.560E+09	3.196	1.894E-02	β	^{106}Pd
^{107}Pd	46	6.5E+06 y	5.143E-04	9.3E-03	5.5E-05	β	^{107}Ag
^{110}Ag	47	24.6 s	4.169E+09	1.216	7.208E-03	β (99.70%); EC (0.30%)	^{110}Cd; ^{110}Pd
^{110m}Ag	47	249.76 d	4.750E+03	2.815	1.669E-02	β (98.64%); IT (1.36%)	^{110}Cd; ^{110}Ag
^{113m}Cd	48	1.37E+01 y	2.168E+02	1.83E-01	1.08E-03	β (99.9%); IT (0.1%)	^{113}In; ^{113}Cd
^{115m}Cd	48	44.6 d	2.546E+04	6.35E-01	3.76E-03	β	^{115}In
^{111}In	49	2.807 d	4.157E+05	4.391E-01	2.603E-03	EC	^{111}Cd
^{113m}In	49	1.658 h	1.673E+07	3.89E-01	2.31E-03	IT	^{113}In
^{114m}In	49	49.51 d	2.313E+04	2.37E-01	1.40E-03	IT (95.7%); EC (4.3%)	^{114}In; ^{114}Cd
^{113}Sn	50	115.09 d	1.004E+04	4.19E-01	2.48E-03	EC	^{113}In
^{117m}Sn	50	13.61 d	7.969E+04	3.19E-01	1.89E-03	IT	^{117}Sn
^{119m}Sn	50	293.0 d	4.478E+03	8.97E-02	5.32E-04	IT	^{119}Sn
^{121m}Sn	50	5.5E+01 y	5.912E+01	4.01E-02	2.43E-04	IT (77.6%); β (22.4%)	^{121}Sn; $^{121}1Sb$
^{123}Sn	50	129.2 d	8.219E+03	5.30E-01	3.14E-03	β	^{123}Sb
^{125}Sn	50	9.64 d	1.084E+05	1.123	6.656E-03	β	^{125}Sb
^{126}Sn	50	~1E+05 y	2.837E-02	1.82E-01	1.08E-03	β	^{126}Sb
^{124}Sb	51	60.20 d	1.749E+04	2.242	1.329E-02	β	^{124}Te
^{125}Sb	51	2.73 y	1.032E+03	5.69E-01	3.37E-03	β	^{125}Te
^{126}Sb	51	12.4 d	8.360E+04	3.102	1.839E-02	β	^{126}Te
^{126m}Sb	51	19.0 min	7.854E+07	2.180	1.292E-02	β (86%); IT (14%)	^{126}Te; ^{126}Sb

Table B.1 (continued)

Radionuclide	Atomic number	Half-life[b]	Specific activity (Ci/g)	"Q" value[c] (MeV/dis)	"Q" value[c] (W/Ci)	Principal mode(s) of decay[d]	Daughter(s)
^{123m}Te	52	119.7 d	8.870E+03	2.501E-01	1.482E-03	IT	^{123}Te
^{125m}Te	52	58 d	1.801E+04	1.466E-01	8.690E-04	IT	^{125}Te
^{127}Te	52	9.35 h	2.639E+06	2.29E-01	1.36E-03	β	^{127}I
^{127m}Te	52	109 d	9.432E+03	9.32E-02	5.52E-04	IT (97.6%); β (2.4%)	^{127}Te; ^{127}I
^{129}Te	52	1.160 h	2.094E+07	6.05E-01	3.58E-03	β	^{129}I
^{129m}Te	52	33.6 d	3.013E+04	3.03E-01	1.80E-03	IT (64%); β (36%)	^{129}Te; ^{129}I
^{123}I	53	13.2 h	1.940E+06	2.004E-01	1.188E-03	EC	^{123}Te
^{125}I	53	60.14 d	1.737E+04	6.02E-02	3.57E-04	EC	^{125}Te
^{129}I	53	1.57E+07 y	1.765E-04	8.04E-02	4.77E-04	β	^{129}Xe
^{131}I	53	8.040 d	1.240E+05	5.74E-01	3.40E-03	β	^{130}Xe
^{133}Xe	54	5.245 d	1.872E+05	1.82E-01	1.08E-03	β	^{133}Cs
^{134}Cs	55	2.062 y	1.294E+03	1.719	1.019E-02	β	^{134}Ba
^{135}Cs	55	3.0E+06 y	1.151E-03	5.6E-02	3.3E-04	β	^{135}Ba
^{137}Cs	55	3.00E+01 y	8.698E+01	1.88E-01	1.11E-03	β	^{137m}Ba; ^{137}Ba
^{133}Ba	56	1.054E+01 y	2.500E+02	4.587E-01	2.719E-03	EC	^{133}Cs
^{137m}Ba	56	2.552 min	5.379E+08	6.64E-02	3.94E-03	IT	^{137}Ba
^{141}Ce	58	32.50 d	2.848E+04	2.48E-01	1.47E-03	β	^{141}Pr
^{144}Ce	58	284.9 d	3.190E+03	1.11E-01	6.58E-04	β	^{144}Pr
^{143}Pr	59	13.58 d	6.731E+04	3.15E-01	1.87E-03	β	^{143}Nd
^{144}Pr	59	17.28 min	7.555E+07	1.238	7.338E-03	β	^{144}Nd
^{144m}Pr	59	7.2 min	1.814E+08	5.8E-02	3.4E-04	IT (99.96%); β (0.04%)	^{144}Pr; ^{144}Nd
^{146}Pm	61	5.53 y	4.428E+02	8.47E-01	5.02E-03	EC (66.1%); β (33.9%)	^{146}Nd; ^{146}Sm
^{147}Pm	61	2.6234 y	9.270E+02	6.2E-02	3.7E-04	β	^{147}Sm
^{148}Pm	61	5.370 d	1.643E+05	1.298	7.691E-03	β	^{148}Sm
^{148m}Pm	61	41.29 d	2.136E+04	2.156	1.278E-02	β (95.4%); IT (4.6%)	^{148}Sm; ^{148}Pm
^{151}Sm	62	9.0E+01 y	2.631E+01	1.25E-01	7.41E-04	β	^{151}Eu
^{152}Eu	63	1.333E+01 y	1.729E+02	1.290	7.646E-03	EC (72.08%); β (27.92%)	^{152}Sm; ^{152}Gd
^{154}Eu	63	8.8 y	2.699E+02	1.532	9.081E-03	β	^{154}Gd
^{155}Eu	63	4.96 y	4.651E+02	1.28E-01	7.59E-04	β	^{155}Gd
^{153}Gd	64	241.6 d	3.526E+03	1.414E-01	8.381E-04	EC	^{153}Eu
^{160}Tb	65	72.3 d	1.129E+04	1.381	8.186E-03	β	^{160}Dy

Table B.1 (continued)

Radionuclide	Atomic number	Half-life[b]	Specific activity (Ci/g)	"Q" value[c] (MeV/dis)	"Q" value[c] (W/Ci)	Principal mode(s) of decay[d]	Daughter(s)
^{169}Yb	70	32.02 d	2.414E+04	4.238E-01	2.512E-03	EC	^{169}Tm
^{175}Hf	72	70.0 d	1.066E+04	4.079E-01	2.418E-03	EC	^{175}Lu
^{182}Ta	73	115.0 d	6.253E+03	1.508	8.940E-03	β	^{182}W
^{192}Ir	77	73.831 d	9.211E+03	1.029	6.099E-03	β (95.4%); EC (4.6%)	^{192}Pt; ^{192}Os
^{201}Tl	81	3.046 d	2.132E+05	1.40E-01	8.30E-04	EC	^{201}Hg
^{207}Tl	81	4.77 min	1.904E+08	4.95E-01	2.93E-03	β	^{207}Pb
^{208}Tl	81	3.053 min	2.945E+08	3.972	2.354E-02	β	^{208}Pb
^{209}Pb	82	3.253 h	4.544E+06	1.98E-01	1.17E-03	β	^{209}Bi
^{211}Pb	82	36.1 min	2.468E+07	5.20E-01	3.083E-03	β	^{211}Bi
^{212}Pb	82	10.64 h	1.389E+06	3.20E-01	1.90E-03	β	^{212}Bi
^{211}Bi	83	2.14 min	4.184E+08	6.607	3.916E-02	α (99.727%) β (0.273%)	^{207}Tl; ^{211}Po
^{212}Bi	83	1.0092 h	1.465E+07	2.783	1.649E-02	α (35.94%); β (64.06%)	^{208}Tl; ^{212}Po
^{213}Bi	83	45.59 min	1.934E+07	6.66E-01	3.95E-03	α (2.16%); β (97.84%)	^{209}Tl; ^{213}Po
^{212}Po	84	2.98E-07 s	1.774E+17	8.784	5.207E-02	α	^{208}Pb
^{213}Po	84	4.2E-06 s	1.261E+16	8.375	4.964E-02	α	^{209}Pb
^{215}Po	84	1.780E-03 s	2.948E+13	7.386	4.378E-02	α	^{211}Pb
^{216}Po	84	1.50E-02 s	3.482E+11	6.779	4.018E-02	α	^{212}Pb
^{217}At	85	3.23E-02 s	1.610E+12	7.065	4.188E-02	α	^{213}Bi
^{219}Rn	86	3.96 s	1.301E+10	6.874	4.075E-02	α	^{215}Po
^{220}Rn	86	55.6 s	9.223E+08	6.288	3.727E-02	α	^{216}Po
^{222}Rn	86	3.825 d	1.538E+05	5.489	3.254E-02	α	^{218}Po
^{221}Fr	87	4.9 min	1.772E+08	6.393	3.789E-02	α	^{217}At
^{223}Fr	87	21.8 min	3.868E+07	4.58E-01	2.71E-03	β	^{223}Ra
^{223}Ra	88	11.43 d	5.121E+04	5.905	3.500E-02	α	^{219}Rn
^{224}Ra	88	3.66 d	1.593E+05	5.687	3.371E-02	α	^{220}Rn
^{225}Ra	88	14.2 d	3.920E+04	1.19E-01	7.08E-04	β	^{225}Ac
^{226}Ra	88	1.600E+03 y	9.887E-01	4.784	2.836E-02	α	^{222}Rn
^{228}Ra	88	5.75 y	2.340E+02	1.16E-02	6.88E-05	β	^{228}Ac

Table B.1 (continued)

Radionuclide	Atomic number	Half-life[b]	Specific activity (Ci/g)	"Q" value[c] (MeV/dis)	"Q" value[c] (W/Ci)	Principal mode(s) of decay[d]	Daughter(s)
^{225}Ac	89	10.0 d	5.803E+04	5.793	3.434E-02	α	^{221}Fr
^{227}Ac	89	2.177E+01 y	7.233E+01	8.00E-02	4.74E-04	β (98.62%); α (1.38%)	^{227}Th; ^{223}Fr
^{228}Ac	89	6.13 h	2.242E+06	1.471	8.719E-03	β	^{228}Th
^{227}Th	90	18.718 d	3.073E+04	6.067	3.596E-02	α	^{223}Ra
^{228}Th	90	1.913 y	8.196E+02	5.423	3.214E-02	α	^{224}Ra
^{229}Th	90	7.340E+03 y	2.127E-01	4.896	2.902E-02	α	^{225}Ra
^{230}Th	90	7.54E+04 y	2.109E-02	4.665	2.765E-02	α	^{226}Ra
^{231}Th	90	1.0633 d	5.316E+05	2.02E-01	1.20E-03	β	^{231}Pa
^{232}Th	90	1.405E+10 y	1.097E-07	4.005	2.374E-02	α	^{228}Ra
^{234}Th	90	24.10 d	2.316E+04	2.52E-02	1.49E-04	β	^{234}Pa
^{231}Pa	91	3.276E+04 y	4.723E-02	5.011	2.970E-02	α	^{227}Ac
^{233}Pa	91	27.0 d	2.075E+04	3.98E-01	2.36E-03	β	^{233}U
^{234m}Pa	91	1.17 min	6.868E+08	8.35E-01	4.95E-03	β (99.87%); IT (0.13 %)	^{234}U; ^{234}Pa
^{232}U	92	6.89E+01 y	2.140E+01	5.307	3.146E-02	α	^{228}Th
^{233}U	92	1.592E+05 y	9.680E-03	4.821	2.857E-02	α	^{229}Th
^{234}U	92	2.454E+05 y	6.248E-03	4.773	2.829E-02	α	^{230}Th
^{235}U	92	7.037E+08 y	2.161E-06	4.576	2.712E-02	α	^{231}Th
^{236}U	92	2.342E+07 y	6.469E-05	4.491	2.662E-02	α	^{232}Th
^{238}U	92	4.468E+09 y	3.362E-07	4.205	2.492E-02	α	^{234}Th
^{236}Np	93	1.550E+05 y	1.317E-02	3.38E-01	2.00E-03	EC (91%); β (8.9%); α (0.20%)	^{236}U; ^{236}Pu; ^{232}Pa
^{237}Np	93	2.140E+06 y	7.049E-04	4.857	2.879E-02	α	^{233}Pa
^{239}Np	93	2.355 d	2.320E+05	4.26E-01	2.53E-03	β	^{239}Pu
^{236}Pu	94	2.851 y	5.313E+02	5.767	3.418E-02	α	^{232}U
^{238}Pu	94	8.774E+01 y	1.712E+01	5.4998	3.2593E-02	α	^{234}U
^{239}Pu	94	2.411E+04 y	6.216E-02	5.101	3.024E-02	α	^{235}U
^{240}Pu	94	6.563E+03 y	2.279E-01	5.155	3.056E-02	α	^{236}U
^{241}Pu	94	1.44E+01 y	1.030E+02	5.2E-03	3.1E-05	β	^{241}Am
^{242}Pu	94	3.763E+05 y	3.818E-03	4.900	2.904E-02	α	^{238}U
^{244}Pu	94	8.26E+07 y	1.774E-05	4.576	2.712E-02	α (99.875%); SPF (0.125%)	^{240}U; (fission products)
^{241}Am	95	4.327E+02 y	3.432	5.539	3.283E-02	α	^{237}Np
^{242}Am	95	16.01 h	8.084E+05	1.96E-01	1.16E-03	β (82.7%); EC (17.3%)	^{242}Cm; ^{242}Pu
^{242m}Am	95	1.41E+02 y	9.718	6.84E-02	4.05E-04	IT (99.55%); α (0.45%)	^{242}Am; ^{238}Np
^{243}Am	95	7.380E+03 y	1.993E-01	5.3137	3.1496E-02	α	^{239}Np

Table B.1 (continued)

Radionuclide	Atomic number	Half-life[b]	Specific activity (Ci/g)	"Q" value[c] (MeV/dis)	"Q" value[c] (W/Ci)	Principal mode(s) of decay[d]	Daughter(s)
^{242}Cm	96	162.94 d	3.306E+03	6.0541	3.5885E-02	α	^{238}Pu
^{243}Cm	96	2.85E+01 y	5.162E+01	6.083	3.605E-02	α (99.76%); EC (0.24%)	^{239}Pu; ^{243}Am
^{244}Cm	96	1.811E+01 y	8.090E+01	5.798	3.437E-02	α	^{240}Pu
^{245}Cm	96	8.5E+03 y	1.717E-01	5.614	3.328E-02	α	^{241}Pu
^{246}Cm	96	4.73E+03 y	3.072E-01	5.385	3.192E-02	α	^{242}Pu
^{247}Cm	96	1.56E+07 y	9.278E-05	5.263	3.119E-02	α	^{243}Pu
^{248}Cm	96	3.40E+05 y	4.251E-03	4.6524	2.7577E-02	α (91.74%); SPF (8.26%)	^{244}Pu; (fission products)
^{252}Cf	98	2.645 y	5.378E+02	5.9371	3.5191E-02	α (96.908%); SPF (3.092%)	^{248}Cm; (fission products)

[a]Based on refs. 6-8.

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

[c]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.

[d]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.

APPENDIX C. MISCELLANEOUS RADIOACTIVE MATERIALS

APPENDIX C. MISCELLANEOUS RADIOACTIVE MATERIALS

C.1 INTRODUCTION

This appendix lists most of the remaining spent fuel and TRU radioactive waste materials not reported in Chapters 1 or 3. They are now stored at DOE and commercial sites and will possibly require geologic disposal. 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 (3) "TRU"-type commercial wastes. Data for the following materials are not included because they do not fit in the category: 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 (1) special-case wastes, (2) spent fuel disassembly hardware and nonfuel-bearing components, and (3) high-activity sources. The term "special-case wastes" was coined in 1988 when DOE Order 5820.2A enacted a comprehensive plan for managing its radioactive wastes.[1] The Order addresses the three major categories of radioactive waste: high-level, low-level, and transuranic. However, some wastes had characteristics of more than one of the major types and were called special-case wastes. The Radwaste Technical Support Program, managed by EG&G Idaho, Inc., was initiated and asked to identify 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 8 × 8 only); control rod guide tubes (PWR assemblies only); and various nuts, washers, and springs. Other 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.

The map of Fig. C.1 shows the current locations of MRM, and Fig. C.2 compares the masses of MRM now stored at the various sites. As seen in Fig. C.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.

C.2 INVENTORIES

Table C.1 summarizes the inventory of MRM that may require geologic disposal. These materials are presently stored at various sites throughout the United States. Tables C.2 through C.9 describe the separate materials at each site in more detail. The data presented in Tables C.1 through C.9 (derived from refs. 5–14) will be useful in planning for final disposal of these materials in a repository.

Inventories of special radioactive materials stored at INEL are given in Table C.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 nonstandard fuels.

Data for the unusual spent fuels now being stored at SRS are included in Table C.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.[14]

Estimated current and projected inventories of TRU wastes from commercial sources are reported in Table C.10. This information is based on refs. 15–18.

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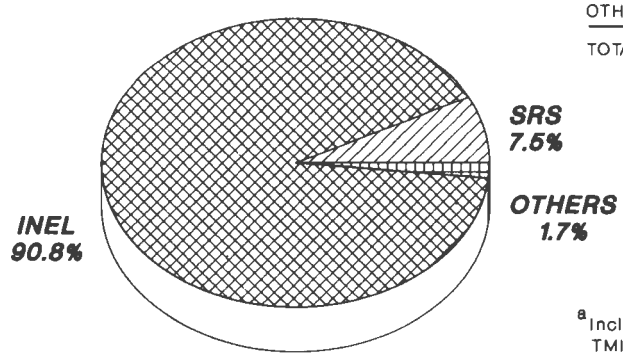
ORNL DWG 90-8298

*Includes contribution from both PNL and 200 Area burial grounds.
**Includes contributions from ANL-W, ICPP, NRF, and other facilities.

Fig. C.1. Locations and total masses of miscellaneous radioactive materials through 1989.

ORNL DWG 90-8299

SITE	HEAVY METAL (METRIC TONS)
INEL	230.6[a]
SRS	19.1
OTHERS	4.3
TOTAL	254.0



[a]Includes 82 t from TMI - Unit 2

Fig. C.2. Mass and locations of miscellaneous radioactive materials as of December 31, 1989.

ORNL DWG 90-8300

FUEL TYPE	HEAVY METAL (METRIC TONS)
Intact	162.6
Damaged	80.1
Scrap	10.1
U-233	1.3
TOTAL	254.0

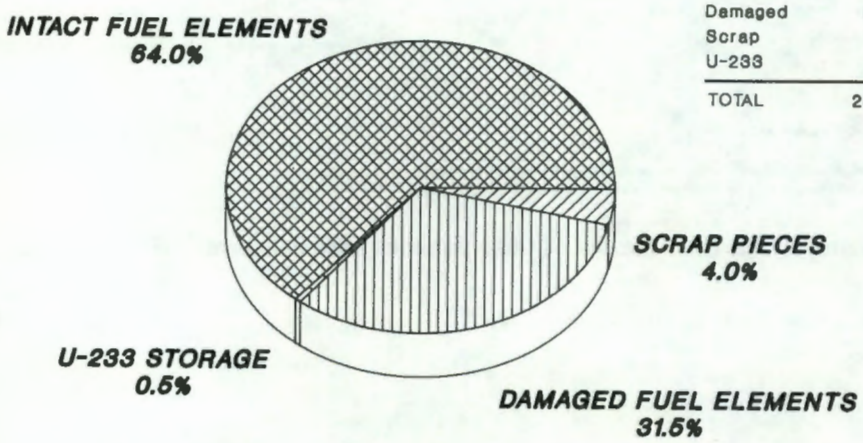


Fig. C.3. Types of miscellaneous radioactive materials.

Table C.1. Inventory of miscellaneous radioactive materials that may require geologic disposal, as of December 31, 1989

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, Naval Nuclear Fuel Division (NNFD) Research Laboratory; Lynchburg, VA	88.45	87.66	1.379		0.790	
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	263.33	230.35	42.21		32.98	
Idaho National Engineering Laboratory; Idaho Falls, ID[b]	148,560.16	81,339.36	1,936.47	959.46	273.80	66,947.0
Los Alamos National Laboratory; Los Alamos, NM	38.03	31.68	22.45	0.134	6.35	
Oak Ridge National Laboratory; Oak Ridge, TN	1,253.72	1,252.92	798.7	280.29	0.801	
Savannah River Site; Aiken, SC	19,110.39	10,419.52	761.04	31.16	42.67	8,648.2
Total reported	171,973.58	95,976.04	3,603.90	1,271.04	395.64	75,601.9
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 145 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 C.2. Miscellaneous radioactive materials stored at Argonne National Laboratory-West, as of December 31, 1989[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 C.3. Miscellaneous radioactive materials stored at Babcock & Wilcox, NNFD Research Laboratory, as of December 31, 1989[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 × 33-in. Al canisters	47,000	11.761	0.046	0.133
B&W Test Reactor	UO_2, Zr-clad	Stored in fourteen 4.25-in.-diam × 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 × 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 × 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	10.579	0.037	0.117
Oconee I	UO_2-Gd_2O_3, Zr-clad	Stored in four 4.25-in.-diam × 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 × 33-in. Al canisters	17,000	10.711	0.105	0.095
			31,000	6.329	0.057	0.056
			36,000	2.105	0.015	0.019
TMI-Unit 2	UO_2 debris	Stored in a 4.25-in.-diam × 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 × 33-in. Al canister	Unknown[c]	2.908	0.757	<0.0005
Hot cell solid waste	Miscellaneous[d]	Stored in forty-one 80-gal drums, thirty-three 55-gal drums, and fifty-two 30-gal drums	-	e	e	<0.082[f]
Total				87.662	1.379	0.790

[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 C.4. Miscellaneous radioactive materials stored at Battelle Pacific Northwest Laboratory, as of December 31, 1989[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 × 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 C.5. Miscellaneous radioactive materials stored at the Hanford 200 Area burial grounds, as of December 31, 1989[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 × 59.5-in. shielded carbon steel casks	45.53	7.64	3.60
From LANL	UO_2/PuO_2, SS-clad	Stored in eight 30-in.-diam × 59.5-in. shielded carbon steel casks	29.18	17.57	14.19
From INEL and FFTF (Fast Flux Test Facility) at Hanford	UO_2/PuO_2, SS-clad	Stored in five 30-in.-diam × 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. × 65.5-in. × 65.5-in. concrete casks	40.49	4.88	4.70
K reactor	Unknown	12 americium target elements stored in one 30-in.-diam × 69-in. Zircaloy container	0.024[c]	0.024	.074
LWR from GETR,[d] Monticello Reactor, Quad Cities 1 Reactor, and Millstone Reactor	UO_2 pellets	Stored in six 30-in.-diam × 59.5-in. shielded carbon steel casks	63.28	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 × 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			230.35	42.21	32.98

[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 C.6. Miscellaneous radioactive materials stored at the Idaho National Engineering Laboratory, as of December 31, 1989[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	One SS tube, 5 in. × 25.5 in.		0.984	0.918			
LWBR (Shippingport Light-Water Breeder Reactor)	Ceramic pellets, Zr-clad, Th blanket	65 units		982.173	10.349	826.016	0.177	56,167.0
Misc. fuels and scrap	Scrap	Stored in 92 SS and Al cans		168.195	137.330	0.119	0.079	36.0
PWR Core 2 (Shippingport Pressurized-Water Reactor)	UO_2 pellets, Zr-clad	28 units		392.026	305.802			
SM-1A (Stationary Media)	UO_2, SS-clad	Stored in 93 SS cans		65.759	56.648			
TORY-11A	UO_2-BeO crushed to 0.25 in. × 0.06 in.	Stored in 147 Al cans 3.25 in. × 1.5 in.		48.645	45.325			
TORY-11C	UO_2-Y_2O_3-ZrO_2-BeO ceramic	Stored in three Al cans 2.68 in. × 52.5 in.		59.065	55.022			
Subtotal				1,716.847	611.394	826.135	0.256	56,203.0
DOE/Civilian Development Programs material stored at ICPP								
EBR Scrap (Experimental Breeder Reactor)	Scrap			1.618	0.839			
Fermi 1 Blanket	U-Mo (97% U), sodium-bonded, SS-clad	Stored in 510 SS cans, 0.4-in. diam × 41 in. or 61 in.		34,165.000	120.000		6.522	
FSVR (Fort St. Vrain Reactor)	U-Th carbide and Th carbide, pyrolytic carbon-coated particles in graphite matrix	732 hexagonal graphite blocks 14.2 in. across flats × 31.2 in.		299.758	164.431	87.013	0.752	8,124.0
Pathfinder	UO_2-B_4C pellets, SS-clad	417 rods in 17 cans; each can is 9-in. diam × 80 in.		53.406	49.242			

Table C.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)								
Peach Bottom	U-Th carbide, pyrolytic carbon-coated particles in graphite matrix	1,603 graphite blocks 3.5-in. diam × 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. × 3 in. × 35.5 in.		251.431	12.083		0.793	
TRIGA (Training Reactor, Isotopes, General Atomic)	Al- or SS-clad elements	852 units stored in 121 cans		160.974	33.839			
VBWR (Geneva) (Vallecitos Boiling-Water Reactor)	UO_2 and UO_2-TiO_2, SS-clad	142 rods stored in four 6-in.-diam × 36-in. Al cans	8[c]	12.383	2.606			
Subtotal				35,276.990	606.580	133.323	9.037	10,744.0
DOE material stored at NRF[d]								
Shippingport PWR Core 1	UO_2 pellets, Zr-clad	Seed and blanket fuel assemblies	11,100	570.02	1.63		3.4	
Shippingport PWR Core 2	UO_2 wafers, Zr-clad	Seed and blanket fuel assemblies	14,273	1,260.92	164.45		8.9	
Subtotal				1,830.94	166.08		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		378.485	5.204		3.774	
Dresden	UO_2, Zr-clad	54 pins (depleted U)		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			

Table C.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)								
GE (General Electric)	UO_2 pellets, Zr-clad	Pins		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					0.324	
IE (Irradiation Effects)	UO_2 pellets, Zr-clad	Pins	27-17,600	7.833	0.867		0.012	
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	Pins		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	1 assembly and pieces		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	

Table C.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)								
H. B. Robinson	UO_2 pellets, Zr-clad	Pins	28,000	263.916	1.890		2.153	
Saxton	UO_2 pellets, Zr-clad	21 pins	10,400-18,530	7.607	0.660		0.025	
SFD (Severe Fuel Damage)	UO_2 pellets, Zr-clad	143 pins		50.867	2.711		0.150	
TC (Thermocouple)	UO_2 pellets, Zr-clad	Pins	0-<20	6.186	0.683			
TMI-Unit 2	Rubble			(Quantities unknown until entire core received)				
VEPCO (Virginia Electric Power Company)		69 assemblies		30,207.295	242.457		172.695	
Subtotal				42,514.582	552.419		252.203	
Total at INEL				81,339.359	1,936.473	959.458	273.796	66,947.0

[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.

Table C.7. Miscellaneous radioactive materials stored at the Los Alamos National Laboratory, as of December 31, 1989[a]

Source of material	Composition	Description	U content, kg			Total Pu content (kg)
			Total	^{235}U	^{233}U	
EBR-2	U-Pu oxide, carbide or nitride SS-clad fuel rod segments	0.3-in. diam × 13.5 in.[b]	26.08	17.71	0.134	6.35
B&W (Lynchburg, VA)	UO_2 spent fuel elements	Stored in racks	5.60[c]	4.74		
Total			31.68[c]	22.45	0.134	6.35

[a]See ref. 12.
[b]No information regarding the burnup of this fuel is available.
[c]Includes 0.348 kg of ^{236}U.

Table C.8. Miscellaneous radioactive materials stored at the Oak Ridge National Laboratory, as of December 31, 1989

Source of material	Composition[a]	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 × 24-in. SS cans	b	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 × 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 × 8-in. fuel test capsules	1,000-2,000	0.399	0.022		
Monticello	UO_2, Zr-clad	1/2-in.-diam × 6-in. fuel rod sections plus short lengths	40,000	1.00	0.004		0.008
MSRE[c] (Molten Salt Reactor Experiment)	LiF_2-BeF_2-ZrF_2-UF_4	See ref. 13	~5 × 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 × 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 × 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 × 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 × 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 × 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 × 18-in. SS cans	b	6.02		5.89	
CZA-91 from ANL	UO_x powder	Stored in two 3.5-in.-OD × 13-in. SS cans	b	0.881		0.856	
HUA-2A from HEDL	UO_x powder	Stored in five 3.75-in.-OD × 7-in. SS cans	b	0.317		0.307	

Table C.8 (continued)

Source of material	Composition[a]	Description	Estimated burnup (MWd/MTIHM)	U content, kg			Total Pu content (kg)
				Total	^{235}U	^{233}U	
LAE-03	Metal	Stored in one 3-in.-OD × 10-in. SS can	b	0.01		0.01	
RCP-02 from SRO	UO_2 powder	Stored in thirty-two 3.5-in.-OD × 24-in. SS cans	b	11.14		10.72	
RCP-03 from SRO	UO_2 powder	Stored in 140 3.88-in.-OD × 10-in. SS cans	b	67.41		61.61	
RCP-04 from SRO	UF_4-LiF_2 powder converted from UO_2	Stored in six 3.5-in.-OD × 24-in. SS cans	b	3.19		2.92	
RCP-06	U_3O_8-CdO solid cake	Stored in twenty-seven 3.5-in.-OD × 24-in. SS cans	b	65.55		60.60	
RCP-20/JZBL from LANL	U metal chunks	Stored in five 3.5-in.-OD × 24-in. SS cans	b	5.15		5.05	
Total				1,252.92	798.7	280.29	0.801

[a]Zr-clad = Zircaloy-clad.
[b]No information regarding the burnup of this fuel is available.
[c]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. 13. Decommissioning of the MSRE facility is an environmental restoration activity discussed earlier in Chapter 6.

Table C.9. Miscellaneous radioactive materials stored at the Savannah River Site, as of December 31, 1989[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 × 14-ft cans; pieces stored in three 3.5-in.-diam × 1-ft cans	6,500	50.22	0.231			
Carolinas-Virginia Tube Reactor	UO_2-Zr or SS-clad	One bundle of 34 rods in a 5.0-in.-diam × 14-ft can	Unknown	67.37	0.640		0.200	
Dresden	UO_2-ThO_2, SS-clad	Intact assemblies stored in 4.4-in. × 4.4-in. × 135-in. cans	4,000-10,000	683.88	37.545	15.391	1.879	1,857.2
ERR (Elk River Reactor)	UO_2-ThO_2, SS-clad	Assemblies 3.5 in. × 3.5 in. × 81.62 in.	Max. 50,000	224.34	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 × 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. × 2.98 in. × 3.14 in.	600	35.45	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 × 32-in.-long can	6,800-30,000	0.52	0.004		0.003	
Saxton	UO_2-PuO_2, Zr- or SS-clad	567 rods stored in eight 5.0-in.-diam × 14-ft cans and 64 rods stored in one 3.75-in.-diam × 50-in. can	1,000	276.67	1.411		15.408	
	UO_2, Zr-clad	Multiple pins stored in four 5.0-in.-diam × 14-ft cans and one bundle stored in one 12-in.-diam × 14-ft can	1,600	66.79	6.866		0.233	
VBWR (Vallecitos Boiling-Water Reactor)	UO_2, Zr-clad	Stored in four 3.5-in.-diam × 12-in. cans	1,500	4.04	0.998		0.003	
Subtotal				1,421.911	241.061	30.113	17.835	6,675.8

Table C.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/Defense plus other government agencies material stored at SRS								
B&W scrap	UO_2-PuO_2, SS-clad	Stored in 3.5-in.-diam × 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 × 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 × 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. × 3.75 in. × 62.5 in.	1,600	1.73	1.612			
	UO_2, Zr-clad	Assemblies 3.75 in. × 3.75 in. × 62.5 in.	1,600	1,604.30	95.456			
	UO_2-Zr, Zr-clad	Assemblies 3.75 in. × 3.75 in. × 62.5 in.	1,600	5,031.77	73.967		9.092	
	UO_2-ZrO_2-CaO, Zr-clad	Assemblies 3.75 in. × 3.75 in. × 62.5 in.	1,600	28.93	26.651			
	UO_2-PuO_2, Zr-clad	Assemblies 3.75 in. × 3.75 in. × 62.5 in.	1,600	907.39	2.087		13.952	
EPR-1	PuO_2, SS-clad	Pieces stored in 4.5-in.-diam × 32-in. can	Unknown				0.022	
GCRE (Gas-Cooled Reactor Experiment)	UO_2 or UO_2-BeO, Hastelloy-clad	Four 2-in.-diam × 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 × 132 in. Pieces stored in 3.5-in.-diam × 12-in. cans	6,200	863.958	8.294		0.007	
	U-Zr, Zr-clad			37.165	31.590			

Table C.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/Defense plus other government agencies material stored at SRS (continued)								
HTRE (High-Temperature Reactor Experiment)	UO_2-BeO, Nichrome-clad	Segments and pieces of fuel assemblies and test pieces in thirteen 4-in.-diam × 36-in. Al cans		3.698	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)	U, Zr-clad	Stored in three 4.5-in.-diam × 9.25-in. Al cans		0.184	0.171			
ORNL mixed oxide	UO_2-PuO_2, Zr- or SS-clad	Stored in one 3.5-in.-diam × 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 × 15-in. container	18,000	16.429	0.023		0.108	
SPERT-3 (Special Power Excursion Reactor Test)	UO_2, Zr-clad	Stored in three 4.0-in.-diam × 12-ft cans	Unknown	12.64	0.603			
SRE (Sodium Reactor Experiment)	U, Th rods, SS-clad	Stored in 3.5-in.-diam × 110.25-in. cans	10,000	155.24	143.410	1.045		1,972.4
	UC, SS-clad			47.42	4.344		0.016	
SRS (Savannah River Site)	UO_2-PuO_2, Zr-clad	Stored in a 12.0-in.-diam × 14-ft container	Unknown	69.00	0.304		0.161	
ORR-LEU (Oak Ridge Reactor Low Enriched Uranium)	U_3Si_2, Al-clad	Stored in fourteen 3.5-in.-diam × 168-in. Al cans	15,600	95.006	14.960	-	0.537	-
Subtotal				8,997.606	519.975	1.045	24.831	1,972.4
Total				10,419.517	761.036	31.158	42.666	8,648.2

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

Table C.10. Estimated current and projected volumes of TRU wastes from commercial sources[a]

Facility/source	Waste description	Accumulated packaged waste volume as of December 31, 1989 (m^3)	Estimated annual volume addition (m^3/year)	Projected total packaged waste volume (m^3)
1. West Valley Demonstration Project[b]	Rubbish, trash, spent resins and filters, contaminated equipment, contaminated rubble	42[c]	INA[d]	300
2. Nuclear power plants	Resins and filters, sludges, metals			
• TMI-Unit 2 cleanup[e]		0	INA[d]	0
• Operating reactors		201	14-25	INA[d]
3. Industrial/institutional	NA[f]			
• Commercial research laboratories		13	0-0.4	NA[f]
• Other industrial users of TRU isotopes		28	11-40	NA[f]
4. Decommissioning programs for commercial fuel fabrication plants	Contaminated glove boxes, tanks, process equipment and piping, laboratory equipment[g]	~256[g]	INA[d]	0
5. Dry rod consolidation at a federal facility	NA[f]	INA[d]	315[h]	NA[f]
Total		~540	340-380.4	300[i]

[a]Data from ref. 15 except where noted.
[b]Data from ref. 16.
[c]Includes 14 m^3 (and 13.2 Ci) of TRU waste generated during 1989.
[d]INA = information not applicable.
[e]Data from ref. 17.
[f]NA = not available.
[g]Waste inventory at the Cimarron Fuel Fabrication Facility (ref. 18).
[h]Waste generation rate, assuming that spent fuel is consolidated at the rate of 3000 MTU/year. These wastes could be generated at a potential MRS facility or at a geologic repository.
[i]Total volume reported is probably low due to lack of data.

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 for site operations (Phone number)[a]	DOE operations/field office (Phone number)[a]
Ames Laboratory	Ames	Ames, IA	Iowa State University (515/294-1856)	Chicago Operations (708/972-2000)
Argonne National Laboratory-East	ANL-E	Argonne, IL	University of Chicago (708/972-2000)	Chicago Operations (708/972-2000)
Argonne National Laboratory-West	ANL-W	Idaho Falls, ID	University of Chicago (208/526-7228)	Chicago Operations (708/972-2000)
Brookhaven National Laboratory	BNL	Upton, NY	Associated Universities, Inc. (516/282-2123)	Chicago Operations (708/972-2000)
Feed Materials Production Center	FMPC	Fernald, OH	Westinghouse Materials Company of Ohio, Inc. (513/738-6200)	Oak Ridge Operations Fernald Area Office (513/738-6200)
Fermi National Accelerator Laboratory	FNAL	Batavia, IL	University Research Association (708/840-3401)	Chicago Operations (708/972-2000)
Hanford Site	HANF	Hanford, WA	Westinghouse Hanford Company, Inc. (509/376-7511)	Richland Operations (509/376-7411)
Idaho National Engineering Laboratory	INEL	Idaho Falls, ID	EG&G Idaho, Inc. (208/526-9822)	Idaho Operations (208/526-0111)
Inhalation Toxicology Research Institute	ITRI	Albuquerque, NM	Lovelace Foundation (505/844-2203)	Albuquerque Operations (505/844-0011)
Kansas City Plant	KCP	Kansas City, MO	Allied Signal, Inc. Kansas City Division (816/997-2000)	Albuquerque Operations Kansas City Area Office (816/997-3348)
Lawrence Livermore National Laboratory	LLNL	Livermore, CA	University of California (415/422-1100)	San Francisco Operations (415/273-4428)
Los Alamos National Laboratory	LANL	Los Alamos, NM	University of California (505/667-5061)	Albuquerque Operations Los Alamos Area Office (505/667-5061)
Mound Plant	Mound	Miamisburg, OH	EG&G Mound Applied Technologies (513/865-4020)	Albuquerque Operations Dayton Area Office (513/865-4020)
Nevada Test Site	NTS	Mercury, NV	Reynolds Electrical & Engineering Company, Inc. (702/295-1000)	Nevada Operations (702/295-1000)
Oak Ridge Associated Universities	ORAU	Oak Ridge, TN	---	Oak Ridge Operations (615/576-3000)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor for site operations (Phone number)[a]	DOE operations/field office (Phone number)[a]
Oak Ridge Gaseous Diffusion Plant	ORGDP	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/576-5454)	Oak Ridge Operations (615/576-0639)
Oak Ridge National Laboratory	ORNL	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge Operations (615/576-5454)
Oak Ridge Y-12 Plant	Y-12	Oak Ridge, TN	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge Operations (615/576-5454)
Paducah Gaseous Diffusion Plant	PAD	Paducah, KY	Martin Marietta Energy Systems, Inc. (502/444-6311)	Oak Ridge Operations (615/576-5454)
Pantex Plant	PANT	Amarillo, TX	Mason & Hanger – Silas Mason Company, Inc. (806/477-3000)	Albuquerque Operations (505/844-0011) Amarillo Area Office (806/381-3000)
Pinellas Plant	Pinellas	Largo, FL	General Electric Company (813/541-8001)	Albuquerque Operations (505/844-0011) St. Petersburg Area Office (813/541-8691)
Portsmouth Gaseous Diffusion Plant	PORTS	Portsmouth, OH	Martin Marietta Energy Systems, Inc. (615/574-1000)	Oak Ridge Operations (615/576-5454) Portsmouth Area Office (614/289-0111)
Princeton Plasma Physics Laboratory	PPPL	Princeton, NJ	Princeton University (609/243-2000)	Chicago Operations (708/972-2000)
Rocky Flats Plant	RFP	Golden, CO	EG&G Inc. (303/966-7000)	Albuquerque Operations (303/966-7000)
Sandia National Laboratories Albuquerque	SNLA	Albuquerque, NM	AT&T Technologies, Inc. (505/844-5678)	Albuquerque Operations (505/844-0011)
Livermore	SNLL	Livermore, CA	AT&T Technologies, Inc. (415/422-7011)	Albuquerque Operations (505/844-0011)
Santa Susana Field Laboratory	SSFL	Canoga Park, CA	Rockwell International Rocketdyne Division (818/710-6300)	San Francisco Operations (415/273-4428)

Table D.1 (continued)

Site/facility	Symbol/label	Location	Principal contractor for site operations (Phone number)[a]	DOE operations/field office (Phone number)[a]
Savannah River Site	SRS	Aiken, SC	Westinghouse Savannah River Company (803/725-6211)	Savannah River Operations (803/725-6211)
Three Mile Island-Unit 2 Reactor	TMI-Unit 2	Middletown, PA	General Public Utilities (717/948-1037)	Idaho Operations Three Mile Island Site Office (717/948-1037)
Waste Isolation Pilot Plant	WIPP	Carlsbad, NM	Westinghouse Electric Corporation WIPP Project Office (505/885-8883)	Albuquerque Operations WIPP Project Office (505/885-8883)
West Valley Demonstration Project	WVDP	West Valley, NY	Westinghouse Electric Corporation West Valley Nuclear Services (716/942-3235)	Idaho Operations West Valley Project Office (716/942-4314)

[a]Phone number for access to main organizations.

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

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 feet deep or more.

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.

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.

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.

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 that 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 toxic, corrosive, flammable, or reactive chemicals above maximum permissible levels as defined by the Environmental Protection Agency in 40 CFR Part 261.3.

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

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 either (1) is listed as a hazardous waste in Subpart D of 40 CFR Part 261 or (2) causes the LLW to exhibit any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261.

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 which 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 that 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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