CHARACTERISTICS OF SPENT NUCLEAR FUEL

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Introduction

The Office of Civilian Radioactive Waste Management (OCRWM) is responsible for the spent fuels and other wastes that will, or may, eventually be disposed of in a geologic repository. The two major sources of these materials are commercial light-water reactor (LWR) spent fuel and immobilized high-level waste (HLW). Other wastes that may require long-term isolation include non-LWR spent fuels and miscellaneous sources such as activated metals. This report deals with spent fuels, but for completeness, the other sources are described briefly.

Detailed characterizations are required for all of these potential repository wastes. These characterizations include physical, chemical, and radiological properties. The latter must take into account decay as a function of time. In addition, the present inventories and projected quantities of the various wastes are needed. This information has been assembled in a Characteristics Data Base which provides data in four formats: hard copy standard reports, menu-driven personal computer (PC) data bases, program-level PC data bases, and mainframe computer files.

This data base is an integral part of the Systems Integration approach being used by OCRWM. In support of this, it provides a standard set of self-consistent data to the various areas of responsibility within OCRWM, including systems integration and waste stream analysis, storage, transportation, and geologic disposal. The data will be used for design studies, trade-off studies, and system optimization by OCRWM and their supporting contractors.

This task was initiated, on a small scale, in 1985 and the first report was published in 1986, including one PC data base.[1] The work was expanded in 1986 to cover the full scope of candidate wastes, and the first draft report was issued that year. Subsequently, two additional draft versions were issued and, finally, the formal report was issued in eight volumes and two printings[2]. A summary of this work is given in the following sections, with major empahsis on spent nuclear fuels.

Overview

The Characteristics Data Base is organized on the basis of four waste stream categories: LWR Spent Fuel, Immobilized High-Level Waste, Non-LWR Spent Fuels, and Miscellaneous wastes. These can be further broken down into eight waste streams (Fig. 1). For HLW, the generator site identities are retained, and the basic units are individual canisters of immobilized HLW. For LWR spent fuel, the basic units are the individual assemblies, and the distinctions between BWRs and PWRs warrant separation on this basis; the generating reactors are also identified. For non-LWR spent fuels and miscellaneous wastes, the as-stored characteristics are the present basis, but as predisposal treatment and packaging concepts are developed, these will be incorporated.

The above four major categories, plus a summary, comprise the five major sections of the hard copy report[2], which was recently issued as an 8-volume set. Six of these volumes consist of 16 appendices that provide supporting information to the other two volumes.

Five of the appendices are Users' Guides to as many menu-driven PC data bases. No programming skills are required to use these, which are described in Table 1. Two more such data bases are under development, one with data on LWR fuel pin characteristics and one for LWR assembly serial numbers. These data bases are designed for use on an IBM-PC or PC-compatible hardware. They are available through the Oak Ridge National Laboratory; ordering information is given in the report[2] on page v.

The above data bases, as well as many of the internal working files, are written in dBASE III PLUS. This permits tabulation of special reports and interactive output.

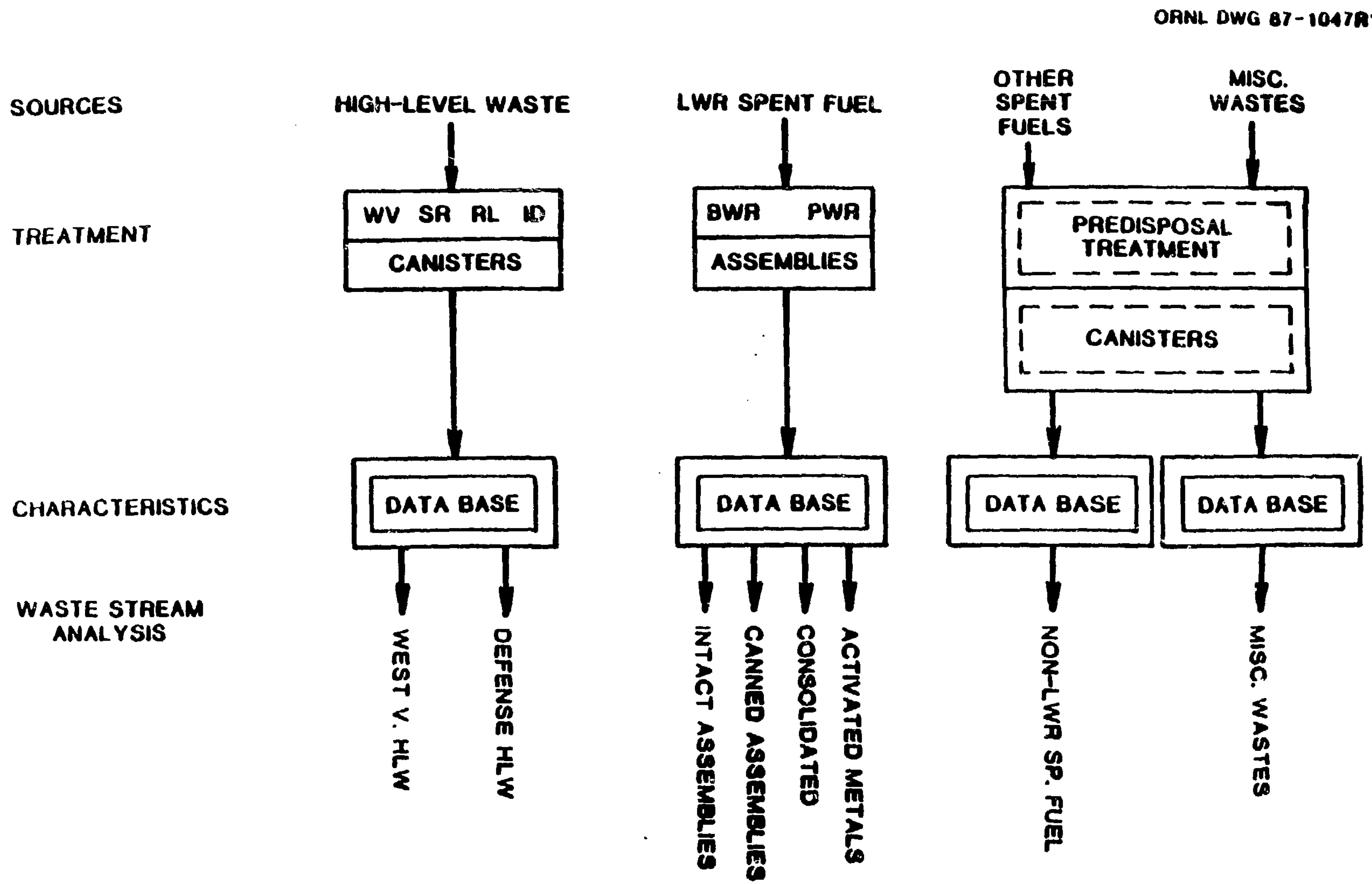

FIG. A-1 GENERIC DATA SOURCES FOR THE CHARACTERISTICS DATA BASE

Table 1. Menu-driven PC Data Bases Available from the Characteristics Data Base

LWR Radiological Data Base - Contains radionuclide compositions, heat generation rates, curies, photon spectra, and other information as a function of spent fuel type, burnup, and decay time.

LWR Assemblies Data Base - Contains detailed physical descriptions of fuel assemblies and radiological properties of spent fuel disassembly (SFD) hardware.

High-Level Waste Data Base - Contains physical, chemical, and radiological descriptions of high-level waste, both as the interim form and the immobilized form in canisters.

LWR NFA Hardware Data Base - Contains physical and radiological descriptions of nonfuel assembly hardware; i.e. nonfuel-bearing hardware other than SFD hardware.

LWR Quantities Data Base - Contains data on discharged fuel, as historical inventories and as projected quantities, based on EIA data supplied to them by the utilities.

Mainframe files are used to generate some of the above files and some of the hard copy reports. Their use involves SAS and FORTRAN. A generalized flow chart for data processing is shown in Fig. 2.

The radiological properties are calculated using ORIGEN2[3], and include:

- quantities of each nuclide (grams or gram atoms);
- radioactivity, total and by nuclide (curies);
- thermal power, total and by nuclide (watts);
- photon energy spectra, by energy group (18 groups);
- neutrons from spontaneous fission (per second);
- neutrons from (alpha, n) reactions (per second); and
- quantity of each element (grams or gram atoms).

The above properties are decayed over time, for 24 (or more) time periods from 1-yr to 1-million years. An interpolation function is provided for those users who may need data at intermediate times. For LWR spent fuel, the integral heats are also available, between any two times out of a set of 38 times, also spanning 1- to 1-million years.

LWR Spent Fuel

Data on LWR spent fuel constitutes the largest portion of the overall data base, because of the large quantities of material involved and because of the complexity of the data. The data base must deal with 78 (at present) different assembly types or models, over a wide range of fuel burnups (5 to 60 GWd/MTU), both actually discharged and projected for future discharge, and the radiological properties over time not only for the fuel itself, but also for the associated hardware. In addition, although most of this fuel is presently in the form of uncanned intact assemblies, some is canned and more of this can be expected (for defective fuel), and future practices may result in extensive disassembly and consolidation, which will also give rise to activated metals from the hardware components.

Figure A3 shows schematically the flow of input and output data for LWR spent fuel. More detailed information on this part of the data base is provided in Chapter 2 of ref. 2.

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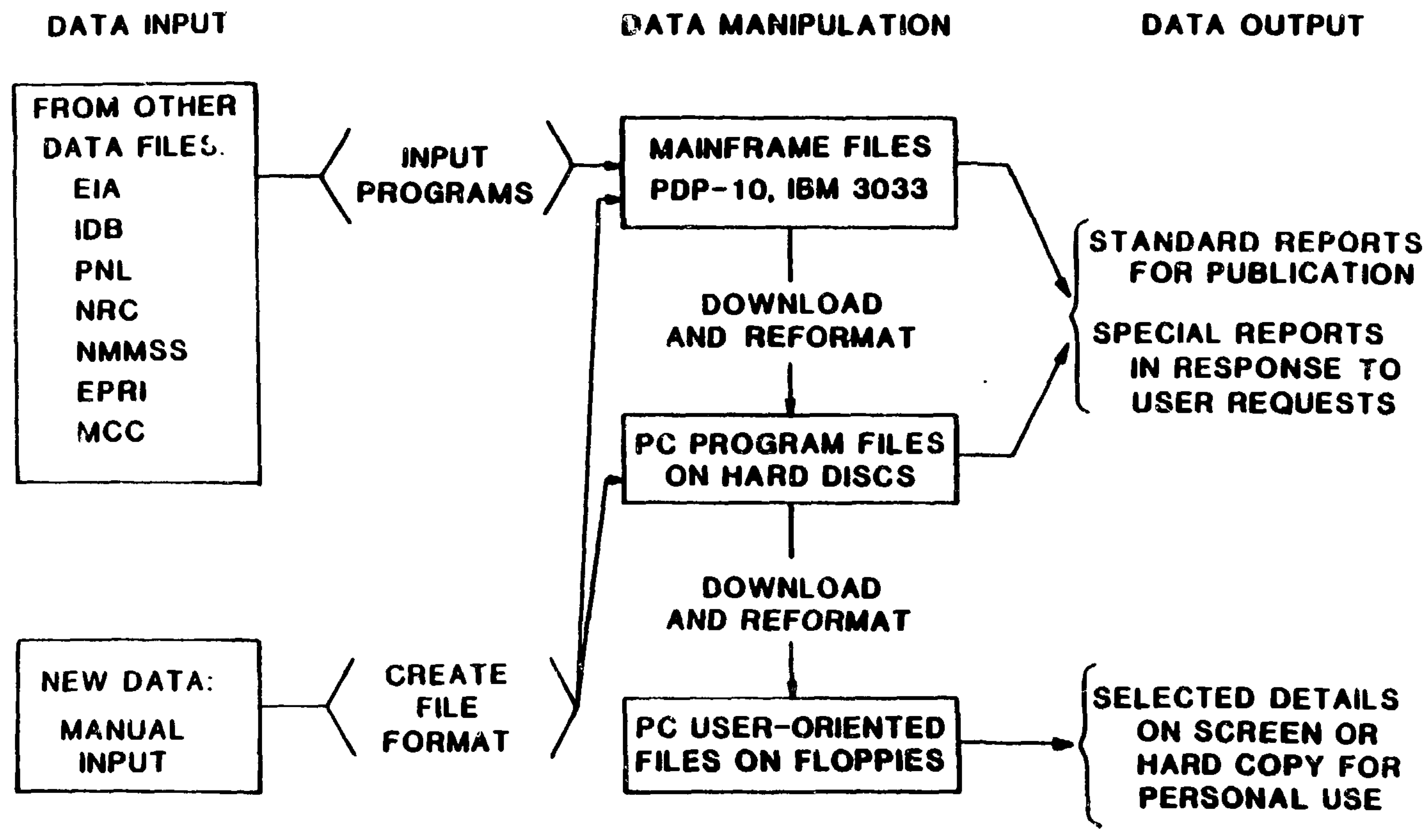

FIG. A-2 DATA FLOW IN THE CHARACTERISTICS DATA BASE

ORNL DWG 88-209R3

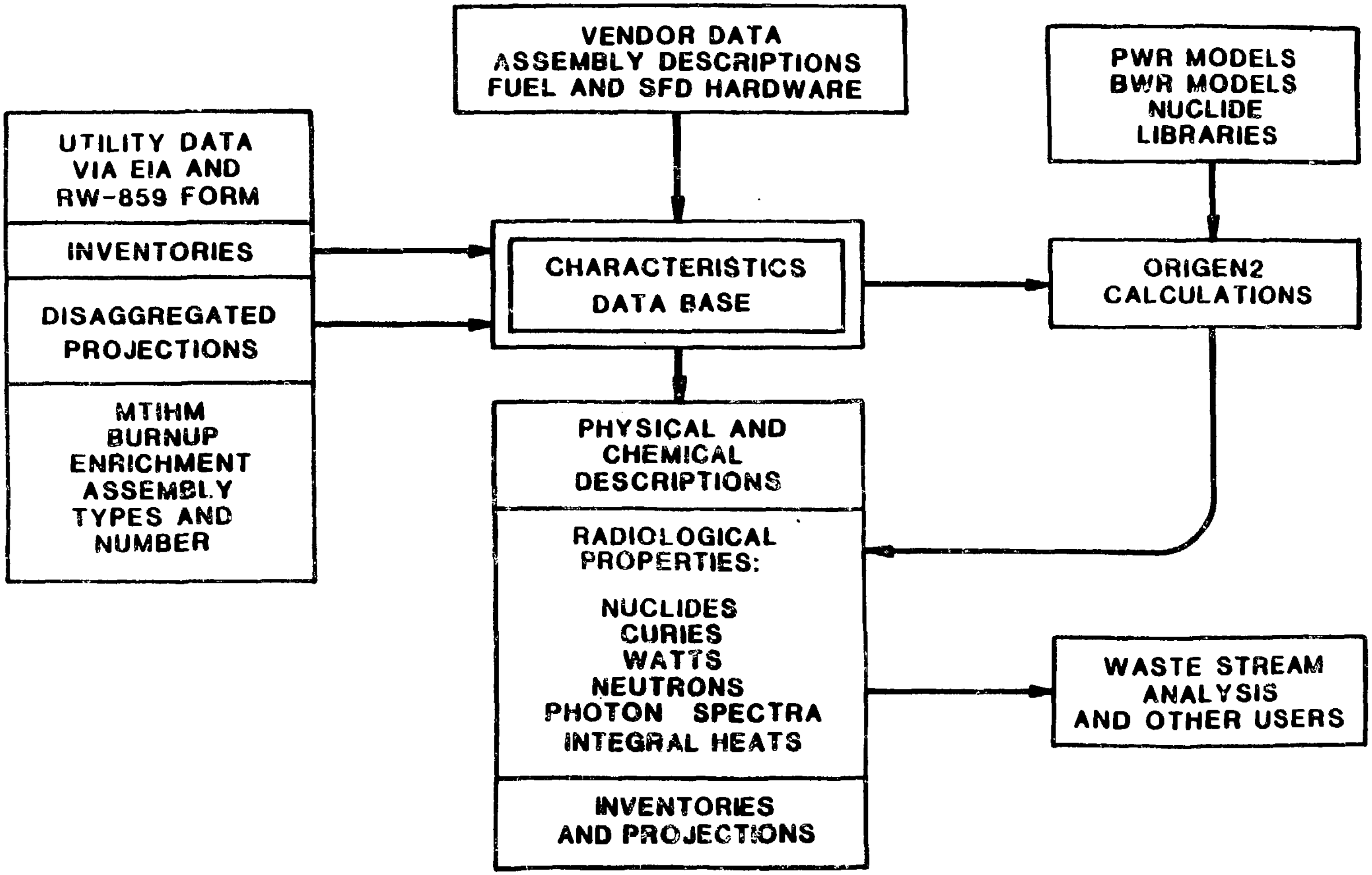

FIG. A-3 CHARACTERISTICS DATA FOR LWR SPENT FUEL

Defective LWR spent fuel is of special interest because it may require special handling procedures, which have not yet been identified, nor have the appropriate waste acceptance criteria been defined. This aspect of the data base is described in Section 2.5 of ref. 2.

Although there are 78 different assembly types listed in the data base, many of these are virtually identical, differing only in minor details or manufacturer, their basic design or configuration being controlled by reactor core design. There are 21 such "assembly classes" (Table 2), plus a number of variants that represent a very limited number of discharged assemblies. A detailed description of this classification scheme has been published.[4] A supplemental report on GE assemblies has also been issued.[5]

High-Level Waste

Immobilized HLW will derive from one commercial operation (West Valley) and three defense sites: Savannah River, Hanford, and Idaho. The first three will produce borosilicate glass by a vitrification process while Idaho, which is storing its HLW in the form of a calcine (rather than liquid, sludge, or salt cake), plans to produce a high-density ceramic waste form. All four sites plan to use canisters 10-ft long by 24-in. in diameter. For completeness, and to utilize existing data, the data base also includes the characteristics of the interim waste forms at the four sites, since this will be the feed material for future immobilized HLW. The data base includes detailed information, year-by-year, on the projected number of canisters and their radiological and thermal properties. A condensed summary of this type data is given in Table 3.

Non-LWR Spent Fuel

This category includes HTGR reactors, research and test reactors, and miscellaneous fuels from various reactors now stored at nine locations. Table 4 gives a summary of these fuels. Note that for the HTGRs the quantity is the number of fuel elements, for the FFTF it is the number of assemblies, while the others are in metric tons of heavy metal (MTHM). The Idaho total does not include the Shippingport breeder core, which contains 770 kg of U, mostly U-233, and 47.21 MT of thorium. In addition, the

Table 2. Major Classes of LWR Assembly Models[a]

Pressurized Water Reactors:

Babcock & Wilcox 15 x 15
Babcock & Wilcox 17 x 17
Combustion Engineering 14 x 14
Combustion Engineering 16 x 16
Westinghouse 14 x 14
Westinghouse 15 x 15
Westinghouse 17 x 17
South Texas 17 x 17 XLR
Palisades 15 x 15
Saint Lucie II 16 x 16
San Onofre I 14 x 14
Yankee Rowe 15 x 16
Indian Point I 13 x 14
Fort Calhoun 14 x 14
Haddam Neck 15 x 15

Boiling Water Reactors:

General Electric BWR/2, 3
General Electric BWR/4, 5, 6
Lacrosse
Big Rock Point
Dresden I
Humboldt Bay

[a]These classes are controlled by reactor core configuration. For PWRs, the array size is fixed because of control rod positions within assemblies. For BWRs, the array size is not fixed because the cruciform control blades operate in between assemblies. For both types there are a number of early, one-of-a-kind reactors, identified by reactor name. Later versions are generic. For each class there are several model types manufactured.

Table 3. Characteristic of Immobilized HLW

		West Valley	Savannah River	Hanford	Idaho
Weight of canister (kg)		252	500	500	500
Weight of contents (kg)		1895	1682	1650	1825
Total weight (kg)		2147	2182	2150	2325
Kilocuries (per canister)[a]		125	234	416	143
Watts (per canister)[a]		380	700	1150	340
Projected startup (year)		1990[b]	1990[b]	1996[b]	2011
Projected No. of canisters (cumulative) in:					
	1992	275	922	0	0
	1995	275	2152	0	0
	2000	275	4202	653	0
	2005	275	5302	1305	0
	2010	275	5890	1860	0
	2015	275	6350	1860	3800
	2020	275	6810	1860	8800

[a]These are maximum values at time of loading. For West Valley, with a fixed input, the average is 10-20% lower. For the defense sites, with future input undefined, the averages may be much lower than the maximum values listed.

[b]Unofficial updates have adjusted these dates to 1992 and 1999, respectively.

Table 4. Summary of Non-LWR Spent Fuels

Reactor/site	Quantities[a]
HTGRs:	
Peach Bottom I	
Core I	804 elements
Core II	804 elements
Fort St. Vrain	725 elements
Research/Test Reactors:	
MTR Plate Fuel	-
TRIGA	-
UO_2-in-Polyethylene	-
PULSTAR	-
FFTF	170 assemblies
Miscellaneous Fuels:	
Argonne	0.31 MTHM
Babcock & Wilcox	0.05 MTHM
Battelle-Columbus	1.50 MTHM
Battelle-PNL	2.25 MTHM
Hanford	0.07 MTHM
Idaho	38.06 MTHM
Los Alamos	0.13 MTHM
Oak Ridge	1.28 MTHM
Savannah River	19.02 MTHM

[a]Data as of December 31,1987.

HTGR fuel is also at the Idaho facility. The thermal outputs of these spent fuels are generally quite low. However, the diversity of chemical compositions and physical configurations, coupled with the high enrichments of many, may impose some challenging packaging and disposal considerations.

Miscellaneous Wastes

This category includes wastes that are neither spent fuel nor HLW, but which may not qualify for commercial low-level disposal, nor as defense TRU waste. In the absence of intermediate depth disposal or greater-confinement disposal, these materials may be future candidates for consideration for repository disposal. Thus, they are included in the Characteristics Data Base, in order to provide technical data on these materials. Many of them are in the category of Greater-than-Class-C Low-Level Waste, and are not eligible for shallow-land burial without an exemption from the Nuclear Regulatory Commission. Wastes presently included in this section are OCRWM-generated wastes, commercial TRU waste, reactor decommissioning waste, radioisotope capsules, and certain LWR operational wastes.

Future Work

A major revision and update of the entire report is planned for 1989, after comments from current users have been received. This revision will include two additional PC data bases, on LWR Fuel Pin Characteristics and on LWR Assembly Serial Numbers. Descriptive data on recently-introduced LWR assembly models will be added and all inventories and projections will be updated. Improved descriptions of HLW will be incorporated. Radiological calculations for LWR fuel and hardware will be improved, using improved cross section and enrichment data for fuel and newly developed activation parameters for activated hardware.

References

1. J. W. Roddy, et al., "Physical and Decay Characteristics of Commercial LWR Spent Fuel," ORNL/TM-9591, January 1986.

2. "Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation," DOE/RW-0184, Vols. 1-6 (December 1987) and Vols. 7-8 (June 1988):

Volume 1.	Summary, LWR Spent Fuel, and Immobilized High-Level Waste.	
Volume 2.	App. 1A	ORIGEN2 Overview
	App. 1B	ORIGEN2 Library Data
	App. 1C	ORIGEN2 Interpolation Functions
Volume 3	App. 2A	Physical Descriptions of LWR Fuel Assembly
Volume 4.	App. 2B	User's Guide to the LWR Assemblies Data Base
	App. 2C	User's Guide to the LWR Radiological Data Base
	App. 2D	User's Guide to the LWR Quantities Data Base
Volume 5.	App. 2E	Physical Descriptions of LWR NFA Hardware
	App. 2F	User's Guide to the High-Level Waste PC Data Base
Volume 6.	App. 3A	ORIGEN2 Decay Tables for Immobilized High-Level Waste
	App. 3B	Interim High-Level Waste Forms
	App. 3C	User's Guide to the High-Level Waste PC data Base
Volume 7.	Non-LWR Spent Fuels and Miscellaneous Wastes	
Volume 8.	App. 4A	Nuclear Reactors at Educational Institutions in the United States
	App. 4B	Data Sheets for Nuclear Reactors at Educational Institutions
	App. 4C	Supplemental Data for St. Vrain Spent Fuel
	App. 4D	Supplemental Data for Peach Bottom 1 Spent Fuel

3. A. G. Croff, "ORIGEN2 - A Revised and Updated Version of the Oak Ridge Isotope Generation and Depletion Code," ORNL-5621, July 1980, and "A User's Manual for the ORIGEN2 Computer Code," ORNL/TM-7175, July 1980.

4. R. S. Moore, D. A. Williamson, and K. J. Notz, "A Classification Scheme for LWR Fuel Assemblies," ORNL/TM-10901, November 1988.

5. R. S. Moore, "Physical Characteristics of GE Fuel Assemblies," ORNL/TM-10902, April 1989.