SPENT FUEL AND RADIOACTIVE WASTE: AN INTEGRATED DATA BASE OF INVENTORIES, PROJECTIONS, AND CHARACTERISTICS*

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ABSTRACT

The Integrated Data Base (IDB) Program provides official U.S. Department of Energy (DOE) data on spent fuel and radioactive waste inventories, projections, and characteristics. This information is provided through the cooperative efforts of the IDB Program and DOE lead offices, lead sites, major programs, and generator sites. The program is entering its fifth year, and major accomplishments are summarized in three broad areas: (1) the annual inventory report, including ORIGEN2 applications and a Quality Assurance (QA) plan; (2) the summary data file and direct user access; and (3) data processing methodology and support to other programs. Plans for future work in these areas are outlined briefly, including increased utilization of personal computers. Some examples of spent fuel data are given in terms of projected quantities for two growth scenarios, burnup and age profile of the existing inventory, and the approximate specific thermal power relative to high-level waste (HLW) from various sources.

INTRODUCTION

The U.S. DOE sponsors the IDB Program in order to provide official DOE data on spent fuel and radioactive waste inventories, projections, and characterisitcs. The program collects information from DOE lead sites, generator sites, and other sources and integrates the information to produce consistent inventories, tabulations of characteristics, and technically rational projections. The program is aided by a Steering Committee, which has members from all major DOE operating sites and DOE lead laboratories in spent fuel and radioactive waste programs. The information received is verified and reviewed to ensure accuracy. It is then collated and made available, as required, to serve various needs. Because of the broad scope of the Program, DOE sponsorship has been shared by the Office for Nuclear Energy and the Office for Defense Programs; recently, the newly formed Office of Civilian Radioactive Waste Management has also become a sponsor.

The IDB Program provides inventories, characteristics, and projections of all types of commercial and government spent fuel and radioactive wastes. Figure 1 illustrates the major source functions and broad categories of source classification. Physically, the materials are described in the following categories and subcategories:

spent fuel (PWR, BWR, other power reactors, special fuels);

high-level waste (liquid, sludge, salt cake, slurry, calcine, capsules, glass);

transuranic waste (buried, contact-handled, remotely handled);

low-level waste (buried, other disposal methods);

uranium mill tailings.

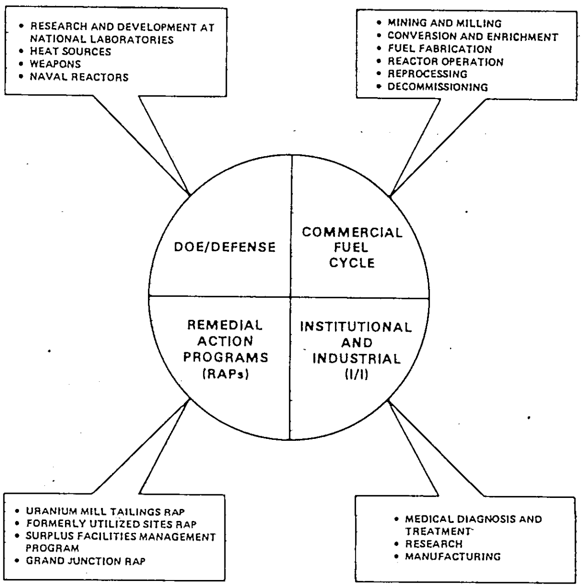

Fig. 1. The IDB Program includes data on all domestic sources of spent fuel and radioactive waste.

*Research sponsored by the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

For all waste forms, inventories and projections are given in terms of waste volume, curies, and watts. Where appropriate, other units of measurement are shown such as mass of transuranic (TRU) elements (in TRU waste) and metric tons of uranium (in spent fuel). Radionuclide compositions are given, and radioactive decay accounted for. The locations of storage or disposal sites are shown. Projections of both spent fuel and radioactive waste are made through the year 2020. Reactor and fuel cycle waste projections are based on the DOE Energy Information Administration (EIA) scenarios for nuclear reactors.

The overall flow of data and the major collating and integrating functions are shown in Fig. 2. Data from many sources are utilized, and feedback is provided to these sources. Inventory data are updated annually, on a calendar-year basis, and historical data and continuity are maintained. Projected values, as well as the isotopics of spent fuel and decayed waste, are calculated. This information constitutes the core data files, from which output is extracted in various formats and to varying levels of detail, as required.

OVERVIEW

Annual Inventory Report

The annual inventory report[1] has gained widespread recognition and acceptance; it is sometimes referred to as "the blue book" because of the blue cover that has been used since 1981. The 300-page report is distributed to over a thousand recipients via DOE "category" distribution plus direct mailing. Copies are available through the Technical Information Center (TIC) or National Technical Information Service (NTIS). In addition to chapters on spent fuel and each of the waste categories listed in the introduction, the report also includes chapters on airborne waste, remedial action programs, decommissioning, and costs. The latter is to provide a broad economic perspective. Appendices provide source terms and flowsheets, along with an analysis of the age of spent fuel at the time of emplacement in a repository for two scenarios.

The base-case projection scenario assumes future reprocessing, but the report also includes projections for the no-reprocessing situation. The program uses two sets of computer codes, the Nuclear Materials Projection Code and the Waste Treatment Simulation Code, to make these projections.

Extraction of data from the core data files is done via SAS (Statistical Analysis System), which also formats the tables. The tabular data are then printed out onto photomasters via a word processor that is hard-wired to our computer mainframe. In the future, the report will include more information on costs and analysis, the source terms appendix will be expanded and published separately, and formatting will be improved by using a composing machine (driven electronically by the word processor) to enhance readability.

ORIGEN2 Applications

ORIGEN2 codes are used to compute (1) the isotopic content of spent fuel as a function of initial enrichment and burnup and (2) the decayed isotopics (and radioactivity and thermal power) of spent fuel and all waste to the present and for projections. The program maintains ORIGEN2 libraries, updates reactor models, and carries out special ORIGEN2 runs that may be required. A validation study was started, using high-burnup fuel (about 40,000 MWd/MTIHM) from the Oconee-1 reactor, to test the results for certain isotopes, mainly transuranics.

A study was performed to determine the effects of batch averaging, particularly as it influences the calculated TRU content, using data for a discharge batch of 65 assemblies from the Zion-1 reactor. The assembly burnups varied from 27,900 to 35,850 MWd/MTIHM, but the axial variation was, of course, larger. Some curium isotopes were underestimated by about 40%. These experiments are reported elsewhere in these Proceedings.[2]

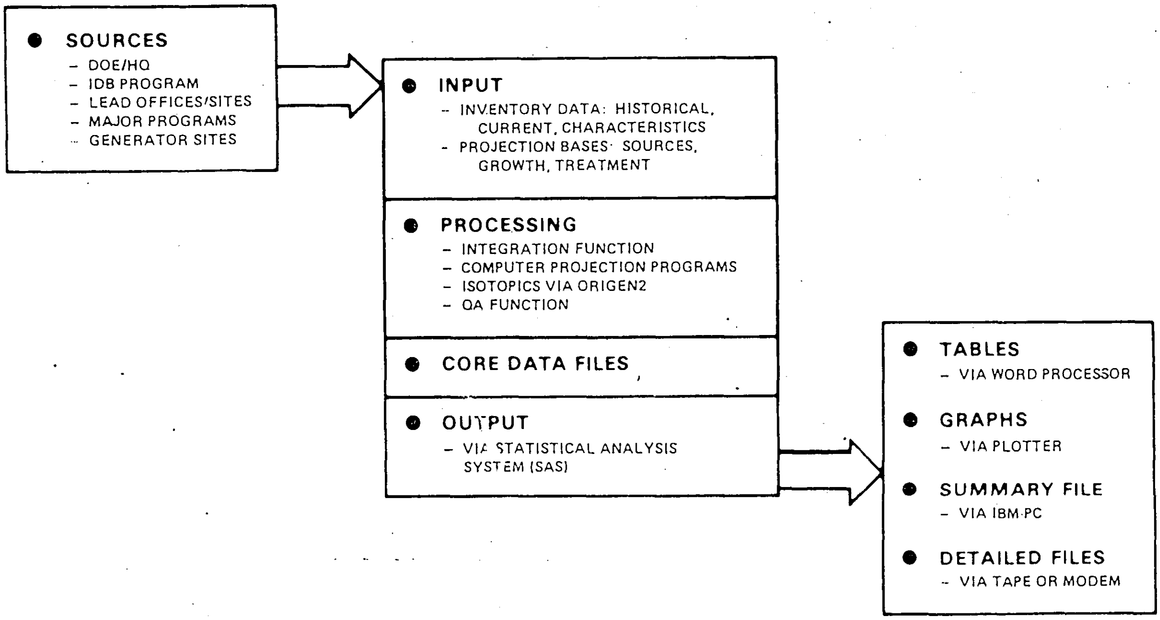

Fig. 2 Conceptual data handling scheme for the IDB Program.

ORIGEN2 is written in FORTRAN and normally run on a large mainframe; however, the new IBM-PC personal computer with expanded memory and numeric coprocessor will handle ORIGEN2. The computation speed will be slower, but queuing is avoided, and the PC is widely available. The decay codes will be transformed to a user-friendly format.

Quality Assurance Plan

A preliminary QA plan was drafted a year ago and reviewed extensively. It has now been issued in draft form to program participants and the Steering Committee for final review and applications testing before being issued as a formal document. QA is important to the program to ensure consistency and continuity, to provide proper documentation of technically rational values, and to provide a visible mechanism for necessary changes to prior data and corrections of any errors.

Summary Data File

The Summary Data File provides, via the IBM-PC and menu-driven, user-friendly programming, essentially all the computerized data in the core files except detailed isotopic compositions. The programming was done last year in dBase II. Two floppy disks are required — one for the program and one for the data. The data disk will be updated each year, in October or November, after the annual report is issued in September. We plan to improve the present programming, which is in dBase II, and perhaps change to K-Man or MDBS III in the future; this will have no impact on the data users other than to provide more flexibility and more options. The Summary Data File will be described and demonstrated at a poster session during this meeting,[3] including a demonstration of graphics capabilities; the core data files are also described in this paper.

Direct User Access

The core data files are accessible to qualified DOE users or DOE contractors via SAS programming. SAS is well-known and in use at most installations. These files include detailed data and ORIGEN2 output. A remote terminal can be used with a modem. As described in the previous section, much of the data are easily accessible through the Summary Data File and an IBM-PC or compatible personal computer (such as the Compaq).

Data Processing Methodology

Generic data flow is illustrated in Fig. 2. The foundation of a good data base rests on individual generator and storage sites. This is where the primary data originates; it is the only source of detailed data down to the package level, and it is where any questions on QA must eventually be resolved. Electronic handling of all data transfers after the original entry, which is a long-term objective of the program, will greatly enhance efficiency, save time and money, and preclude transcription errors. Furthermore, for the more detailed and voluminous data, there really is no other acceptable way. The basic building blocks to achieve this are in place, and data transfer to IDB has been accomplished via magnetic tapes from two sites — one using FORTRAN and the other COBOL. As personal computers are used for site data files (and this is already occurring at three sites), data transfers can be made with floppy disks.

Support to Other Programs

Specialized support was provided in three areas last year: data call by a lead site, waste data files at a generator site, and general consulting on personal computer applications.

At the request of the Transuranic Waste Systems Office (TWSO), a unified annual call for TRU waste data was developed in conjunction with TWSO, the Solid Waste Information Management System (SWIMS), and all of the DOE generator or storage sites for TRU waste. After several iterations, a workshop was held and a consensus reached relative to the specific data content of the actual data call. A major component was to first develop a list of terms and definitions that applied to all the sites in a direct and unambiguous manner; after that, agreement was reached on the data items to be supplied in six different tables. It was also agreed that the storage sites would have responsibility for completing the annual questionnaires, calling on the generator sites as needed.

The general approach used for the IDB Summary Data File was modified and adapted to ORNL-site TRU waste data. The IBM-PC is being used, and the old COBOL files will eventually be phased out. Data entries to the computer will be made (and checked) by the waste operations staff rather than by keypunch operators. Data will be entered on a package-by-package basis, as before, but data retrieval will be much easier. All of the data for ORNL, about 3000 packages, can be stored on one "Winchester" hard disk. It is planned to add LLW data at a later date. The TRU waste data system is described elsewhere in these Proceedings.[4]

Because of program experience and expertise with personal computers, some of our staff have been used as consultants in this field where the data involved are related to IDB data needs. Many sites also use their personal computers for functions other than data base management, for example: word processing, spread sheets, graphics, scheduling, and networking.

SPENT FUEL PARAMETERS

Projected Quantities

The base case used for reactor projections in the annual inventory report[1] is based on the EIA mid-case at that time and gives the projected cumulative spent fuel discharges listed in the second column of Table I. A lower projection was also used in the age analysis, based on reactors at least 35% completed as of June 1983. Events of recent months suggest that the latter is more realistic. However, as indicated in the third column, the difference between the two does not become significant until after 1995, after future reactors are expected to come on-line. Conversely, during the next 15 years, the amount of spent fuel discharged will be largely independent of any additional reactor cancellations. Projections such as these have a direct bearing on planning and scheduling for a repository or monitored retrievable storage.

Burnup-and-Age Profile

Repository planning is also concerned about the thermal output of spent fuel (or the derived HLW) to be emplaced, since thermal load is a limiting factor. Because this is a function of fuel burnup and age, a profile of these quantities was included in the last report;[1] it is shown in condensed form in Table II.

Table I. Total LWR spent fuel discharged for two scenarios[a]

	1983 EIA mid-case[b]	Lower-growth case[c]	Difference
Inventory data:			
1970	65	65	—
1975	1,590	1,590	—
1980	6,635	6,635	—
1982	8,989	8,989	—
Calculated projections:			
1985	13,800	13,600	200
1990	27,100	26,700	400
1995	42,000	40,100	900
2000	57,900	54,800	3,100
2005	75,500	69,000	5,500
2010	98,000	83,000	15,000
2015	122,000	98,000	24,000
2020	148,000	113,000	35,000

[a]Quantities given as MTIHM.
[b]For 128.6 GW(e) in year 2000, with growth to 218.6 GW(e) in year 2020.
[c]For 109.7 GW(e) in year 2000, based on plants at least 35% completed as of June 1983; no further growth after year 2000.

Table II. Burnup and time of discharge of commercial LWR spent fuel in inventory[a]

	Burnup (MWd/MTIHM)								
Year	0 to 5,000	5,000 to 10,000	10,000 to 15,000	15,000 to 20,000	20,000 to 25,000	25,000 to 30,000	30,000 to 35,000	35,000 to 40,000	Totals
1969	—	0.2	0.9	7.1	0.2	7.8	—	—	16.2
1970	—	—	—	40.5	7.8	—	—	—	48.3
1971	—	13.9	10.1	—	—	40.0	—	—	64.0
1972	141.6	11.8	39.2	49.0	—	9.2	21.7	—	272.5
1973	9.1	16.3	35.6	64.3	—	39.7	—	—	165.0
1974	59.9	13.3	198.5	70.6	17.7	74.0	—	—	434.0
1975	—	10.0	232.0	167.1	92.7	41.2	19.8	—	562.8
1976	0.1	49.4	124.5	296.3	83.8	91.3	37.2	—	682.6
1977	—	52.1	34.2	306.0	228.6	134.1	85.9	18.4	859.3
1978	—	1.8	75.6	197.1	311.7	429.9	72.5	62.1	1,150.7
1979	—	—	45.6	215.4	216.6	456.7	238.9	31.6	1,204.8
1980	15.4	—	11.7	45.7	407.7	413.7	226.0	28.8	1,149.0
1981	—	—	25.5	73.2	255.9	465.8	428.1	16.0	1,264.5
1982	—	—	14.5	120.3	118.7	461.4	360.6	13.2	1,088.7
Totals	226.1	168.8	847.9	1,652.6	1,741.4	2,664.8	1,490.7	170.1	8,962.4

[a]Shown in MTIHM. Does not include that reprocessed at West Valley.

A trend is clearly evident, with the more recently discharged fuel having the higher burnup. In 1981-82, the majority of discharged fuel had a burnup that was close to the reference value. This trend can be expected to continue, with the current emphasis on higher burnup and longer cycle time. Thus, while older spent fuel has a lower thermal power per assembly (due both to age and lower burnup), newer fuel can be expected to show the reverse effect. However, for a given quantity of electric power generated (the basis of the repository fee), the thermal load on the repository is about the same, even though there might be fewer assemblies. However, the contained transuranics will be relatively higher at higher burnups since their ingrowth is not linear.

Specific Thermal Power

Data in the annual report[1] allow the calculation of the approximate specific thermal power of spent fuel and various HLW forms (see Table III). For spent fuel and future commercial HLW, it was assumed that the oldest fuel is emplaced or processed first. Consolidated fuel has the end fittings and structural material removed, while HLW also has the cladding removed, both of which decrease the heat load. Except for the Richland capsules (of strontium and cesium), which are a special case, defense HLW and West Valley HLW have a much lower specific thermal power than the major commercial sources, and the total thermal power is much less for all defense sources, including West Valley, which is now a DOE responsibility. Volume reduction factors on vitrification were assumed to be 15 for West Valley, 20 for Richland and Savannah River, and unity for INEL calcine. The extremely low specific thermal power of both INEL HLW and Richland "balance of HLW" suggests that these materials could be considered as high level in name only.

Table III. Approximate specific thermal power for various HLW and spent fuel forms

Site and form	Total thermal power (kW)	Total volume (m^3)	Specific thermal power (W/m^3)
West Valley HLW, converted to glass			
1995	80	160	500
2020	40	160	250
SR HLW, glass from DWPF			
1995	500	2,000	250
2020	2,300	8,700	265
INEL HLW, as calcine or glass			
1995	300	7,500	40
2020	1,300	22,000	60
RL, capsules			
1995	970	10.5	90,000
2020	515	10.5	50,000
RL, balance of "HLW" converted to glass			
1995	800	10,000	80
2020	285	10,000	30
Future commerical HLW as glass			
1995	5,000	830	6,000
2020	54,000	8,000	6,800
Spent fuel from which above derived			
1995 (9,000 MTIHM)	6,000	~4,000	1,500
2020 (94,500 MTIHM)	74,000	~47,000	1,600
Above spent fuel, after consolidation			
1995	5,500	~2,100	2,600
2020	68,000	~25,000	2,700

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