THE CHARACTERIZATION OF SPENT FUEL

TO BE SHIPPED TO A DISPOSAL SITE

G. W. McNair
Battelle Pacific Northwest Laboratory

J. W. Cashwell
Sandia National Laboratories

ABSTRACT

The designs of various components within the spent fuel disposal system are heavily influenced by the characteristics of the products they are going to receive. The storage and disposal facilities are required to estimate the thermal loading on their facilities from the receipt of various quantities of spent fuel. The anticipated thermal loading of the facility feeds directly into the receiving and processing designs and media stress and deformation calculations. In addition to the design of the various facilities, the design of the transportation fleet required to deliver the spent fuel will be directly affected. The quantity of fuel that may be contained within various cask designs are a direct function of the thermal output of the transported fuel. An accurate projection of the thermal characteristics of the spent fuel to be shipped to a given disposal site is of prime importance for ongoing design and planning activities.

A logistics code has been developed at Pacific Northwest Laboratories (PNL) to analyze the interaction of the various facilities within the nuclear waste disposal system. This program tracks spent fuel discharges (historic and projected) from a given reactor fuel basin through a series of facilities that includes Federal Interim Storage (FIS), Fuel Reprocessing Plants (FRP), Monitored Retrievable Storage (MRS), and Mined Geologic Disposal (MGD). The characteristics of the inventory at each of these facilities during any given year is available from the analysis. The majority of the input supplied to the logistics analysis is derived from the DOE Spent Fuel Data Base currently being maintained at PNL.

The logistics model utilizing both historic and projected discharges was used to analyze the characteristics of spent fuel to be shipped to a proposed MGD facility or facilities.

BACKGROUND

The primary planning assumption for the disposal of civilian radioactive wastes is that no reprocessing of commercial spent nuclear fuel will be undertaken in the near future. Therefore, the predominant waste form for the first two repositories will be spent fuel. The eventual details of the disposal system logistics will depend on system design bases and interface considerations. These will be fully examined and taken into account during the development of the disposal program. However, an initial planning base can be developed based on the projected minimum disposal requirements. These minimum disposal requirements derive from the past and projected future operation of existing and planned commercial nuclear power reactors in the United States.

The projections of spent fuel discharges and associated storage and disposal requirements described below are developed from the DOE Spent Fuel Data Base. This data base, updated annually using utility-supplied *historical* and projected fuel management information, was developed and is maintained under DOE's Commercial Spent Fuel Management Program for use in DOE programs. The data below represent an update through December 31, 1982, of the data reported in Spent Fuel Storage Requirements, DOE/RL-83-1 (January 1983).

ANALYSIS

Four systems logistics alternatives were selected as bases for estimating the requirements for spent fuel disposal. The first case assumes that spent fuel will be scheduled to arrive at the repository only on the basis of heat generation (coldest fuel [KW/MT] available in any given year). The second case assumes the schedule is based soley on the basis of age (oldest fuel [years out of reactor] available in any given year). Neither of these cases attempt to detail the storage requirements available at the various reactor facilities. Both of these cases assume that each individual reactor will be able to maintain storage of all the fuel generated at that site until it meets the requirements (oldest/coldest) to be shipped to a disposal facility.

The third case analyzed accounts for projected storage problems that may occur at individual reactor sites. The logistics utilized for this case assumes that the first reactors that exceed their Full Core Reserve (FCR) margins will ship fuel to a Federal Interim Storage (FIS) facility. This amount is limited to 1900 MTU total by the Nuclear Waste Policy Act (NWPA). Reactors that exceed FCR margins subsequent to the receipt of 1900 MTU at FIS, but prior to the opening of the disposal facility, are assumed to provide additional "at-reactor storage". Once the disposal facility begins operation the spent fuel to be delivered to the facility was given priority according to the following schedule.

1) The FIS must be emptied within three years of the start of operations of the disposal facility (assume one-third per year).

2) Reactors exceeding FCR in a given year will be given higher priority.

3) Reactors that terminate in a given year will have all remaining spent fuel shipped to the disposal facility within five years following termination.

4) Oldest fuel remaining in system.

The receipt rate utilized for each of these cases assumed two 70,000 MTU disposal facilities with the first facility becoming operational in 1998 and the second in 2002. Each of these facilities would be phased in over five years at a rate of 1800 MTU per year followed by continuous operation at a rate of 3000 MTU per year until full.

The final case was selected as the basis for estimating the minimum requirements for spent fuel disposal. This case assumes that additional spent fuel storage requirements prior to 1998 will be met by supplemental at-reactor storage. In addition, it is assumed that, after 1998, the disposal system will be capable of accepting sufficient spent fuel to eliminate the need for any further deployment of suplemental at-reactor storage. The disposal system (upon deployment in 1998) receives the minimum amount of fuel required to:

1) preclude additional reactors from losing full core reserve (FCR) storage capacity, and

2) unload, within five years after final reactor shutdown, the storage basins of any reactors being decommissioned.

Case 1 - Coldest Fuel Available

The logistics assumptions utilized in this case include the following:

1) All reactor sites will provide means for storing all spent fuel generated at that site until such time that the fuel is scheduled to be delivered to the disposal facility.

2) Each year a survey is made of all spent fuel remaining in storage throughout the system. This fuel will be ordered according to its heat rate (KW/MT).

3) The coldest fuel available in the system (up to an amount equivalent to the disposal system receipt rate, see table 1), will be shipped to the disposal site.

The results of imposing these constraints on the spent fuel system are shown below, figure 1.

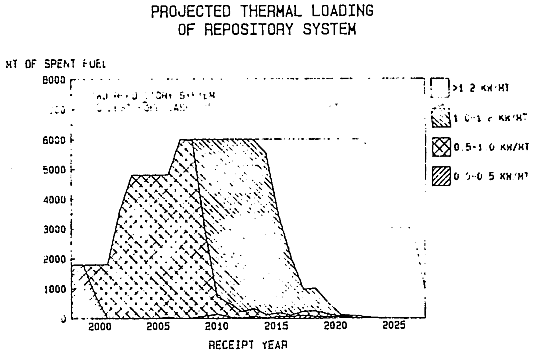

FIG. 1. Disposal Facility Thermal Receipt Rate For Coldest Fuel Case

This figure shows the amount of spent fuel that will be received by the disposal facility as a function of heat rate. In the early years of operation there is sufficient amounts of spent fuel, cooled to very low limits, to allow the processing of spent fuel far below the design basis (1.2 KW/MT). The heat rate of the spent fuel continually increases as the amounts of long cooled fuel is depleted. By approximately 2015, at the assumed receipt rates, the heat rate of the incoming spent fuel has increased to a rate that exceeds the design basis and continues to increase each year. After the year 2015, almost 100 percent of the spent fuel received by the disposal facility will be in excess of the present design basis.

Table I Disposal System Receipt Rate (MT)

YEAR	1ST SITE RECEIPT	2ND SITE RECEIPT	ANNUAL RECEIPT	CUMULATIVE RECEIPT
1998	1800		1800	1800
1999	1800		1800	3600
2000	1800		1800	5400
2001	1800		1800	7200
2002	1800	1800	3600	10800
2003	3000	1800	4800	15600
2004	3000	1800	4800	20400
2005	3000	1800	4800	25200
2006	3000	1800	4800	30000
2007	3000	3000	6000	36000
2008	3000	3000	6000	42000
2009	3000	3000	6000	48000
2010	3000	3000	6000	54000
2011	3000	3000	6000	60000
2012	3000	3000	6000	66000
2013	3000	3000	6000	72000
2014	3000	3000	6000	78000
2015	3000	3000	6000	84000
2016	3000	3000	6000	90000
2017	3000	3000	6000	96000
2018	3000	3000	6000	102000
2019	3000	3000	6000	108000
2020	3000	3000	6000	114000
2021	3000	3000	6000	120000
2022	3000	3000	6000	126000
2023	1000	3000	4000	130000
2024		3000	3000	133000
2025		3000	3000	136000
2026		3000	3000	139000
2027		1000	1000	140000

Case 2 - Oldest Fuel Available

The logistics assumptions utilized in this case include the following:

1) All reactor sites will provide means for storing all spent fuel generated at that site until such time that the fuel is scheduled to be delivered to the disposal facility.

2) Each year a survey is made of all spent fuel remaining in storage throughout the system. This fuel will be ordered according to its age out of reactor.

3) The oldest fuel available in the system (up to an amount equivalent to the disposal system receipt rate, see table I,) will be shipped to the disposal site.

The results of imposing these constraints on the spent fuel system are shown below, figure 2.

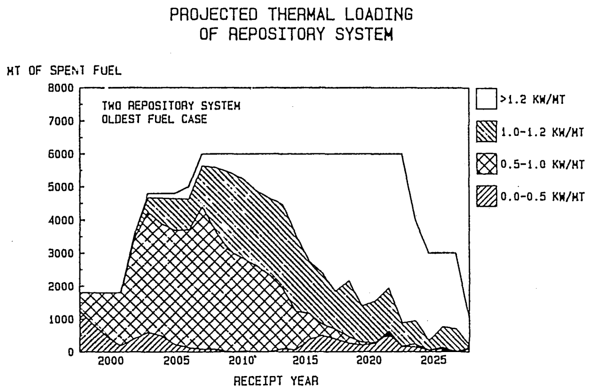

FIG. 2 Disposal Facility Thermal Receipt Rate For Oldest Fuel Case

In the early years of operation, as in case 1, there is sufficient amounts of spent fuel, cooled to very low limits, to allow the processing of spent fuel below the design basis. The average heat rate of the incoming fuel continues to rise to a point where, once again, the majority of the spent fuel will exceed the design basis. The primary difference between this case and the previous case is in the uniformity of the heat distribution within a given year. In the previous case (basing the priority on heat rate) the disposal facility could expect to receive a very uniform distribution of heat rates in any given year. In the present case, due to differences in exposure levels for various batches of discharged fuel, the heat rate of this fuel will show much wider dispersions. The fuel in excess of the design capacity will now arrive at an earlier date (~2003) and gradually increase with time.

Case 3 - FCR Priority

The logistics assumptions utilized in this case are listed above, in the background section. Imposing these priorities into the logistics for the spent fuel system results in a thermal receipt rate as shown below.

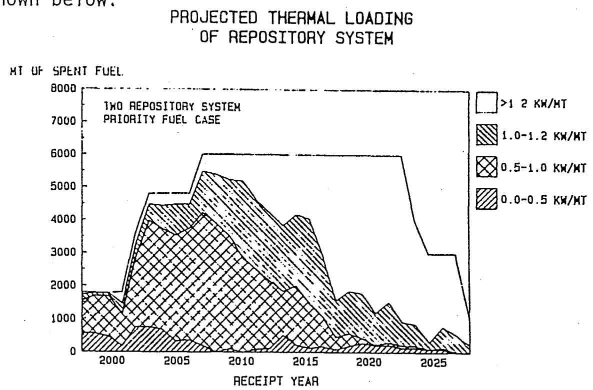

FIG. 3. Disposal Facility Thermal Receipt Rate For Excess Storage Priority Case

The results shown in figure 3 are very similar to the results for case 2 (oldest fuel available). The primary difference being the receipt of a small portion of fuel in excess of the design basis in the first year of operation. This fuel is generated at a reactor site encountering a FCR loss and maintaining less than a ten year storage capacity within its spent fuel basin. Similar to the previous case, the amount of spent fuel exceeding the design basis gradually increases with time. After the year 2015, the amount of spent fuel exceeding the disposal facility design basis is approximately 75-85% of receipt rate.

Case 4 - Minimum Requirements

In the previous three cases the amount of fuel exceeding the design basis of the disposal facility became a very large fraction of the total receipt rate after approximately 2015. This was caused by the large receipt rates assumed for the disposal system. Withdrawing fuel from the spent fuel storage system, at the assumed rates, depletes the system of design base fuel by approximately 2015. The majority of this fuel is above the minimum requirements necessary to maintain reactor facilities in operation with FCR's. Case 4 removes only enough spent fuel to preclude additional reactors from losing FCR storage capacity (after 1998) and unloads the spent fuel basins and additional at-reactor storage from reactor sites five years following termination.

Table II summarizes the basic spent fuel storage data used to evaluate this logistics alternative. A list of the existing and planned reactors assumed for this table, together with detailed information about their storage capacities and projected operations, may be found in DOE/RL-83-1.

Table II shows the projected annual spent fuel discharge for currently existing or planned reactors. The table also shows the amount of fuel which is projected to require placement in supplemental at-reactor storage, storage in FIS, or removal to the disposal facility to preclude the loss of FCR storage capacity at any individual reactor; these estimates are based on the assumption that each reactor basin is reracked to its maximum storage capacity. In addition, the table shows the amount of fuel that must be removed from decommissioned reactors; these estimates assume that all fuel stored onsite, plus the final reactor core loading, must be removed five years after final shutdown. Finally, the total annual and cumulative requirements for out-of-pool storage or disposal of spent fuel are shown.

Table III shows the annual and cumulative requirements for transfer of fuel to the disposal facility for the logistic case described above. This alternative requires the transfer of approximately 22,500 MT of spent fuel to the disposal facility system in the first ten years of operation, and a total of nearly 88,600 MT by 2025. As shown in Table III, some of the fuel placed in supplemental storage before 1998 is withdrawn and transferred to the disposal facility when the particular reactor involved is decommissioned.

Figure 4 shows the heat generation for the fuel to be transferred to the disposal facility. This figure shows that minimum receipt requirements within the first ten years average approximately 2000 MT/year. The peak annual transfer requirement of approximately 9000 MT occurs near 2015, when fuel transfers from decommissioned reactors peak.

The information presented in Table III and Figure 4 provides insight into the minimum design basis for the disposal system. However, it is not sufficient to define a preferred design basis. Any deployment scenario in which the cumulative system receipt always exceed the cumulative requirements as shown in Table III will satisfy the minimum system receipt requirements. However, to the extent that the cumulative receipts exceed the minimum requirements, fuel that is hotter than shown in Figures 4 must be received. The appropriate tradeoff between these two considerations is a design issue that depends on factors other than logistics, and must be fully evaluated during the disposal system design and development process.

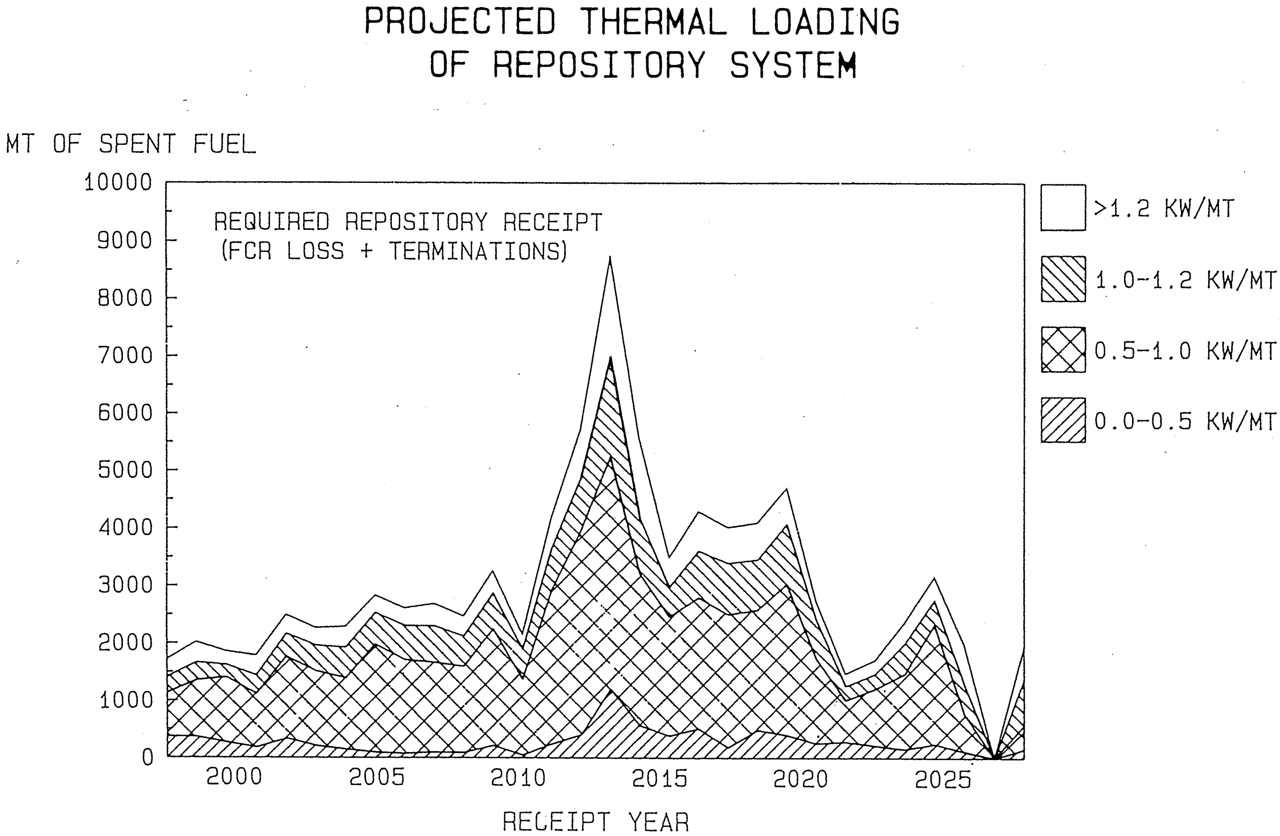

FIG. 4. Minimum Required Repository Receipt

Table II Spent Fuel Discharge Data and Storage/Disposal Requirements

YEAR	ANNUAL DISCHARGE	FUEL TRANSFER TO AVOID FCR LOSS	TRANSFERS FROM DECOMMISSIONED REACTORS	TOTAL ANNUAL	TOTAL CUM.
1983	10,298				
84	1,618	13	-	13	13
85	1,904	-	-	-	13
86	2,208	98	-	98	111
87	2,493	171	-	171	282
88	2,752	201	-	201	483
89	2,572	338	-	338	821
90	3,238	524	-	524	1,345
91	2,931	485	-	485	1,830
92	2,886	648	-	648	2,478
93	3,122	744	-	744	3,222
94	2,993	799	-	799	4,021
95	2,995	1,029	-	1,029	5,050
96	3,208	1,410	-	1,410	6,460
97	3,009	1,305	-	1,305	7,765
98	3,091	1,557	166	1,723	9,488
99	3,412	2,022	-	2,022	11,510
2000	3,163	1,853	-	1,853	13,363
01	2,973	1,782	-	1,782	15,145
02	3,570	2,493	-	2,493	17,638
03	3,368	2,257	-	2,257	19,895
04	3,417	2,287	-	2,287	22,182
05	3,820	2,760	70	2,830	25,012
06	3,908	2,431	168	2,599	27,611
07	4,260	2,685	-	2,685	30,296
08	4,898	2,463	-	2,463	32,759
09	4,167	2,217	939	3,156	35,915
10	4,321	2,144	-	2,144	38,059
11	4,361	2,100	1,785	3,885	41,944
12	4,401	1,873	3,046	4,919	46,863
13	4,656	1,809	6,033	7,842	54,705
14	4,507	1,831	2,803	4,634	59,339
15	4,862	1,655	933	2,588	61,927
16	4,739	1,600	1,793	3,393	65,320
17	4,832	1,644	2,281	3,925	69,245
18	4,990	1,414	2,187	3,601	72,846
19	4,833	1,302	3,311	4,613	77,459
20	4,787	1,253	1,174	2,427	79,886
21	End of Projection Discharge		1,175	1,175	81,061
22			1,635	1,635	82,696
23			1,817	1,817	84,513
24			2,931	2,931	87,444
25			1,814	1,814	89,258
26			-	-	89,258
27			1,711	1,710	90,968

Table III Minimum Requirements Logistics

ANNUAL INVENTORY CHANGE				CUMULATIVE INVENTORY CHANGE		
REQUIREMENTS	DRY STORAGE	DISPOSAL	YEAR	REQUIREMENTS	DRY STORAGE	DISPOSAL
13	13	-	1984	13	13	-
-	-	-	85	13	13	-
98	98	-	86	111	111	-
171	171	-	87	282	282	-
201	201	-	88	483	483	-
338	338	-	89	821	821	-
524	524	-	90	1,345	1,345	-
485	485	-	91	1,830	1,830	-
648	648	-	92	2,478	2,478	-
744	744	-	93	3,222	3,222	-
799	799	-	94	4,021	4,021	-
1,029	1,029	-	95	5,050	5,050	-
1,410	1,410	-	96	6,460	6,460	-
1,305	1,305	-	97	7,765	7,765	-
1,723	-	1,723	98	9,488	7,765	1,723
2,022	-	2,022	99	11,510	7,765	3,745
1,853	-	1,853	2000	13,363	7,765	5,598

Table III Minimum Requirements Logistics (Continued)

ANNUAL INVENTORY CHANGE				CUMULATIVE INVENTORY CHANGE		
REQUIREMENTS	DRY STORAGE	DISPOSAL	YEAR	REQUIREMENTS	DRY STORAGE	DISPOSAL
1,782	-	1,782	2001	15,145	7,765	7,379
2,493	-	2,493	02	17,638	7,765	9,873
2,257	-	2,257	03	19,895	7,765	12,129
2,287	-	2,287	04	22,182	7,765	14,416
2,830	-	2,830	05	25,012	7,765	17,247
2,599	-	2,599	06	27,611	7,765	19,846
2,685	-	2,685	07	30,296	7,765	22,531
2,463	-	2,463	08	32,759	7,765	24,994
3,156	-105	3,261	09	35,915	7,660	28,225
2,144	-	2,144	10	38,059	7,660	30,399
3,885	-313	4,198	11	41,944	7,347	34,597
4,919	-814	5,733	12	46,863	6,533	40,330
7,842	-1740	9,582	13	54,705	4,793	49,412
4,634	-770	5,404	14	59,339	4,023	55,316
2,588	-472	3,060	15	61,927	3,551	58,376
3,393	-624	4,017	16	65,320	2,927	62,393
3,925	-79	4,004	17	69,245	2,848	66,397
3,601	-497	4,098	18	72,846	2,351	70,496
4,613	-91	4,704	19	77,459	2,260	75,199
2,427	-300	2,727	20	79,886	1,960	77,926
1,175	-289	1,464	21	81,061	1,671	79,390
1,635	-75	1,710	22	82,696	1,596	81,100
1,817	-551	2,368	23	84,513	1,045	83,468
2,931	-226	3,157	24	87,444	819	86,625
1,814	-153	1,967	25	89,258	666	88,592
-	-	-	26	89,258	666	88,592
1,710	-266	1,975	27	90,968	400	90,568