COMMERCIAL HIGH-LEVEL WASTE PROJECTIONS

J. O. Blomeke

J. P. Nichols

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

COMMERCIAL HIGH-LEVEL WASTE PROJECTIONS

J. O. Blomeke
J. P. Nichols

MAY 1973

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

COMMERCIAL HIGH-LEVEL WASTE PROJECTIONS

J. O. Blomeke

J. P. Nichols

ABSTRACT

Projections are presented of the high-level solidified wastes to be generated through the end of this century by the U.S. nuclear power industry in the course of reprocessing spent reactor fuels. The installed nuclear electric capacity of the U.S. is taken as 134, 504, and 1200 GW at the end of calendar years 1980, 1990, and 2000, respectively. The reactor complex is assumed to consist of LMFBRs, HTGRs, and U- and Pu-fueled LWRs. It is estimated that the equivalent of 471,000 ft³ of high-level solidified wastes will have been generated through the year 2000, and that by 2010, when all of this waste has been shipped to a federal repository, it will contain 53,000 MCi of activity and evolve heat at a rate of 195 MW.

INTRODUCTION

Projections of the industrial radioactive wastes from the nuclear fuel cycle over the remainder of this century are useful in the planning and design of techniques and facilities needed for their future management, and for the assessment of potential environmental effects. This document summarizes estimates made in November 1972 of the solidified high-level wastes to be generated as a consequence of reprocessing spent fuels. A revision reflecting current AEC forecasts of nuclear power and containing additional details of waste characteristics will be published with projections of other types of fuel cycle wastes in a subsequent report.

The waste estimates are based on the projections of installed nuclear electric capacity and reactor distributions given in Table 1. This table is derived from operating data¹ through FY 1972, the forecast of the AEC Office of Planning and Analysis² from FY 1972 through 1988, and the results of a recent ORSAC case³ (Case 63), thereafter. It also reflects information on nuclear power growth recently developed by the Operational Planning and Power Division, Oak Ridge Operations Office of the AEC,⁴ and comments by the Office of Planning and Analysis on an earlier draft report.⁵

Table 1. Forecast of U.S. Nuclear Electric Power
Generating Capacity, GWe (net)

Year	End of Calendar Year	Average in Fiscal Year			
		LWR	HTGR	LMFBR	Total
1970	5.0 ^a				
71	8.1 ^a	5.2 ^a			5.2
72	17	8.2 ^a			8.2
73	31	17.5			17.5
74	45	31.2			31.2
75	55	45.3			45.3
76	63	55.1			55.1
77	76	62.9			62.9
78	94	76.0			76.0
79	114	94.4			94.4
1980	134	111.7	2.2		113.9
81	159	129.1	5.3		134.4
82	185	149.9	8.8		158.7
83	213	168.1	16.6		184.7
84	245	187.7	25.0		212.7
85	281	209.8	34.9		244.7
86	318	235.0	45.7		280.7
87	362	260.9	56.8		317.7
88	408	289.6	69.1	3.5	362.2
89	453	318.3	81.4	8.5	408.2
1990	504	344.9	92.8	15.5	453.2
91	559	374.0	105.2	25.0	504.2
92	617	404.1	118.1	37.0	559.2
93	676	432.1	130.1	55.0	617.2
94	740	456.3	140.9	79.0	676.2
95	807	476.2	151.1	113.0	740.3
96	879	490.7	160.7	156.0	807.4
97	955	505.0	170.6	203.0	878.6
98	1033	519.7	181.1	254.0	954.8
99	1117	533.1	191.0	309.0	1033.1
2000	1201	546.3	201.2	370.0	1117.5
01	1287	551.1	214.8	435.0	1200.9
02	1376	555.6	227.8	504.0	1287.4
03	1467	551.9	242.8	581.0	1375.7
04	1561	543.2	257.8	665.7	1466.7
05		532.9	272.8	755.8	1561.5

^aOperating data from Nucleonics Week.

ASSUMED NUCLEAR REACTOR CHARACTERISTICS

Tables 2 and 3 present pertinent characteristics of the types of nuclear power reactors that were assumed for this study. The ORSAC code used mass flow data that have been developed for the entire life of the reactor. We have presented only the steady-state mass flows in these tables.

The light-water reactor used in the study is based upon the Diablo Canyon PWR.⁶ It was concluded from separate studies that the high-level wastes from BWR fuel will closely approximate those from PWRs on the basis of equal exposure. Plutonium recycle in the PWR assumes self-sustaining recycle that uses a mixture of assemblies that contain either enriched uranium or plutonium mixed with natural uranium. These assemblies are assumed to be shipped and reprocessed together, such that the plutonium product and wastes will be blended. At steady state: (1) 1.21 atoms of fissile plutonium replaces 1.00 atoms of ^{235}U in the plutonium fueled assemblies; (2) 32.4% of the assemblies in the reactor are fueled with plutonium; and (3) the plutonium used in the plutonium fueled assemblies has an initial fissile content of 61.3%, and fissile content at discharge of 55.4%. The plutonium product produced in the enriched uranium elements (70.64% fissile) is blended with the product of the plutonium elements (55.4% fissile) in order to develop the plutonium for the next refueling (61.3%).

The model HTGR is based upon design studies of an 1160-MW(e) HTGR that uses annual refueling (at 80% capacity factor) of approximately one-fourth of the core.^{7,8} Recycle of ^{233}U is assumed to begin in the third reload. The ^{235}U from the fissile makeup particles is assumed to be reprocessed separate from the ^{233}U -thorium particles and recycled one time before discard. This recycle of partially burned ^{235}U particles is also assumed to begin in the third reload.

The assumed properties of the Atomics International and General Electric Follow-On LMFBR designs are taken from normalized data that were developed by the Argonne National Laboratory.⁹ The A.I. Follow-On Design is assumed to be typical of early LMFBRs that may begin commercial

Table 2. Assumed Characteristics of PWR Fueled with Enriched Uranium,
PWR with Self-sustaining Pu Recycle, and HTGR

	PWR-U	PWR-U, Pu ^a			HTGR			Total
		U Fraction	Pu Fraction	Total	Th- 233U	235U Fresh Makeup	235U Recycled Makeup	
Electric Power, MWe(net)	1000			1000				1160
Thermal Power, MW	3077	2081	996	3077				3000
Avg. Specific Power, ^b MW/metric ton	37.5	37.5	37.5	37.5				80.65
Avg. Burnup, MWd/metric ton	32,873	32,873	32,873	32,873				94,264
Refueling Interval, days ^c	365.25	365.25	365.25	365.25	365.25	365.25	365.25	365.25
Steady-State Charge								
Th, kg	-	-	-	-	8434	-	-	8434
233U, kg	-	-	-	-	217	-	-	217
235U, kg	875.2	592.0	59.8	651.8	29.6	373.0	30.4	433
Total U, kg	27,350	18,500	8409	26,909	357.9	403.0	104.5	865.4
Fissile Pu, kg ^d	-	-	270.3	270.3	-	-	-	-
Total Pu, kg ^e	-	-	441.0	441.0	-	-	-	-
(U + Pu + Th), kg	27,350	18,500	8850	27,350	8792	403.0	104.5	9299.4
Steady-State Discharge								
Th, kg	-	-	-	-	7819	-	-	7819
233U, kg	-	-	-	-	219.3	-	-	219.3
235U, kg	243.4	164.6	26.4	191.0	30.7	30.8	2.6	64.1
Total U, kg	26,137	17,679	8190	25,869	366.1	105.3	70.0	541.4
Fissile Pu, kg ^d	180.1	121.8	151.2	273.1	-	-	-	2.1
Total Pu, kg ^e	254.9	172.4	273.1	445.5	-	-	-	10.0
(U + Pu + Th), kg	26,572	17,851	8463	26,315	8185	105.3	70.0	8370

^aPWR with self-sustaining Pu recycle.

^bBased upon full power and fuel charged.

^cAt 80% load factor.

^d239Pu + 241Pu.

^e238Pu + 239Pu + 240Pu + 241Pu + 242Pu.

Table 3. Assumed Characteristics of A.I. and G.E. Follow-On LMFBRs

	A.I. Follow-On LMFBR				G.E. Follow-On LMFBR			
	Core	Axial Blanket	Radial Blanket	Total	Core	Axial Blanket	Radial Blanket	Total
Electric Power, MWe(net)				1002				1011
Thermal Power, MW	2215	107	74	2400	2081	195	141	2417
Avg. Specific Power, ^a MW/metric ton	116.1	8.1	4.7	50.18	155.6	13.0	8.5	53.76
Avg. Burnup, ^b MWD/metric ton	67,594	4739	7970	37,098	104,542	8725	9051	41,792
Refueling Interval, ^c days	364	364	364	364	385	385	385	385
Steady-State Charge								
²³⁵ U, kg	16	13	5	34	-	20	14	34
Total U, kg	7890	6571	2702	17,163	5038	6884	4798	16,720
Fissile Pu, kg ^d	1196	-	-	1196	786	-	-	786
Total Pu, kg ^e	1663	-	-	1663	1093	-	-	1093
Total (U + Pu), kg	9553	6571	2702	18,826	6131	6884	4798	17,813
Steady-State Discharge								
²³⁵ U, kg	8	11	3	22	-	14	10	24
Total U, kg	7255	6415	2543	16,213	4439	6580	4583	15,602
Fissile Pu, kg ^d	1143	133	119	1395	714	234	163	1111
Total Pu, kg ^e	1655	137	126	1918	1051	245	171	1467
Total (U + Pu), kg	8910	6552	2669	18,131	5490	6825	4754	17,069

^aBased upon full power and fuel charged.^bPer metric ton of fuel charged.^cAt 80% load factor.^d²³⁹Pu + ²⁴¹Pu.^e²³⁹Pu + ²⁴⁰Pu + ²⁴¹Pu + ²⁴²Pu.

operation in the period FY 1988 through FY 1991. The GE Follow-On design is assumed to be typical of advanced LMFBRs that would begin commercial operation after FY 1991.

PROJECTIONS OF THE FUEL REPROCESSING INDUSTRY

Tables 4 and 5 present projections of total U.S. processing loads for each reactor type. The columns labeled "PWR-Pu" in these tables consider only the PWR fuel that was fabricated from plutonium and natural uranium. Table 4 presents actual quantities of uranium, plutonium, and thorium in the spent fuel that is shipped to the reprocessing plant. This table contains some fuel with relatively low exposure (resulting from startup cycles) as well as $\text{UO}_2\text{-PuO}_2$ and $\text{UO}_2\text{-ThO}_2$ scrap that is recycled from fabrication plants. Table 5 is essentially a table of megawatt-days of exposure represented by the fuel reprocessed in a given year since it presents the equivalent tons of fuel assuming that all of the fuel has the rated steady-state exposures. These data are used to develop estimates of the radiation properties of aggregates of spent fuels and wastes based upon ORIGEN calculations of the properties of spent fuels at the rated steady-state exposures.

The startup schedules and performances of the first three reprocessing plants in the U.S. are given in Table 6. This table was constructed using schedules of operating capability supplied by the General Electric Co. (GE), Allied-Gulf Nuclear Services (AGNS), and Nuclear Fuel Services (NFS). The projected reprocessing load will be such that all three plants will not be operating at their full combined operating capacity of 2400 tons/year until FY 1980. Thereafter, new capacity (either through expansion of the existing plants, or from new plants) will be required to keep up with the demand. Reprocessing capabilities of the three plants will be such that the fuel backlog will be worked off by FY 1976, and the distribution of the processing load among the plants until 1980 is conjectural. Except for the PWR-U fuel that is backlogged during the early 1970s, reprocessing occurs 150, 365, and 90 days after discharge from PWR, HTGR, and LMFBR reactors, respectively.

Table 4. Actual Reprocessing Load (Metric Tons of Spent Fuel)

YEAR	PWR-U	PWR-PU	HTR	AIFC	GEFC	TOTAL
1973	50.0	0.0	0.0	0.0	0.0	50.0
1974	250.0	0.0	0.0	0.0	0.0	250.0
1975	850.0	0.0	0.0	0.0	0.0	850.0
1976	1304.8	0.0	0.0	0.0	0.0	1304.8
1977	1277.8	0.0	0.0	0.0	0.0	1277.8
1978	1598.9	0.0	0.0	0.0	0.0	1598.9
1979	1954.7	0.0	3.9	0.0	0.0	1958.6
1980	2125.9	268.9	6.6	0.0	0.0	2401.4
1981	2585.6	453.4	7.7	0.0	0.0	3046.7
1982	2873.5	635.4	36.8	0.0	0.0	3545.6
1983	3233.3	818.4	66.3	0.0	0.0	4118.0
1984	3193.5	1001.5	97.8	0.0	0.0	4292.9
1985	3567.5	1184.5	169.3	0.0	0.0	4921.3
1986	4123.0	1106.1	239.2	0.0	0.0	5468.3
1987	4771.3	917.8	321.1	5.0	0.0	6015.3
1988	5622.3	732.2	406.3	7.1	0.0	6768.4
1989	6449.9	549.1	492.1	77.1	0.0	7568.3
1990	7284.2	366.1	589.6	175.4	0.0	8415.3
1991	7974.8	183.0	683.4	294.5	11.9	9147.6
1992	8999.9	0.0	764.0	474.3	17.8	10256.0
1993	9536.2	0.0	858.1	471.0	238.8	11104.0
1994	10092.3	0.0	954.6	470.8	567.1	12084.7
1995	10478.1	0.0	1040.1	470.7	998.9	12987.9
1996	10871.0	0.0	1115.7	470.6	1602.6	14060.0
1997	11194.4	0.0	1193.2	407.3	2281.9	15076.8
1998	10836.9	0.0	1261.1	380.1	3070.1	15548.1
1999	11179.5	0.0	1332.8	341.4	3928.6	16782.3
2000	11041.5	0.0	1415.1	295.1	4828.0	17579.7
2001	11423.9	0.0	1483.3	465.8	5840.6	19218.6
2002	11183.3	0.0	1553.8	400.6	6837.2	19975.3
2003	11133.7	0.0	1656.0	377.7	7964.8	21132.1
2004	11360.3	0.0	1732.0	340.4	9150.7	22583.4
2005	10642.2	0.0	1812.1	227.7	10450.7	23132.7

Table 5. Reprocessing Load at Rated Exposure (Metric Tons)

YEAR	PWR-U	PWR-PU	HTGR	AIFC	GEFO
1973	29.1	0.0	0.0	0.0	0.0
1974	155.4	0.0	0.0	0.0	0.0
1975	566.9	0.0	0.0	0.0	0.0
1976	967.0	0.0	0.0	0.0	0.0
1977	1086.0	0.0	0.0	0.0	0.0
1978	1406.5	0.0	0.0	0.0	0.0
1979	1722.9	0.0	0.0	0.0	0.0
1980	1937.0	113.5	0.0	0.0	0.0
1981	2338.3	283.7	0.0	0.0	0.0
1982	2661.3	494.9	4.5	0.0	0.0
1983	2972.1	685.5	13.9	0.0	0.0
1984	3020.5	876.1	29.7	0.0	0.0
1985	3346.9	1066.8	60.3	0.0	0.0
1986	3911.3	985.1	102.6	0.0	0.0
1987	4418.6	905.7	158.6	0.0	0.0
1988	5222.1	762.6	227.5	0.0	0.0
1989	6050.7	572.0	306.0	32.9	0.0
1990	6912.2	381.3	392.3	112.7	0.0
1991	7653.5	190.7	483.8	225.4	0.0
1992	8681.3	0.0	577.1	380.3	0.0
1993	9213.8	0.0	673.5	469.5	96.8
1994	9811.1	0.0	771.6	469.5	338.9
1995	10279.8	0.0	869.0	469.5	695.5
1996	10775.8	0.0	964.6	469.5	1190.0
1997	11221.2	0.0	1057.3	403.8	1762.2
1998	10881.2	0.0	1144.4	375.6	2496.2
1999	11234.6	0.0	1227.3	338.0	3308.0
2000	11107.3	0.0	1308.5	291.1	4162.1
2001	11291.3	0.0	1388.4	469.5	5109.8
2002	11193.9	0.0	1451.6	403.8	6052.4
2003	10927.6	0.0	1532.7	375.6	7131.9
2004	11028.9	0.0	1603.8	338.0	8229.6
2005	10287.2	0.0	1664.0	225.4	9445.7

Table 6. Reprocessing Plant Startup Schedules^a

Fiscal Year	Reprocessing Load (Metric Tons)		Fuel Reprocessed (Metric Tons) ^b								New Capacity	
	Annual	Cumulated	GE		AGNS		NFS		Total GE + AGNS + NFS		Annual	Cumulated
			Annual	Cumulated	Annual	Cumulated	Annual	Cumulated	Annual	Cumulated		
1972	140	140	0	0	0	0	0	0	0	0	0	0
73	150	290	50 ^c	50 ^c	0	0	0	0	50	50	0	0
74	425	715	250 ^c	300 ^c	0	0	0	0	250	300	0	0
75	749	1,464	300	600	550	550	0	0	850	1,150	0	0
76	991	2,455	275	875	630	1,180	400	400	1,305	2,455	0	0
77	1,278	3,733	275	1,150	603	1,783	400	800	1,278	3,733	0	0
78	1,599	5,332	280	1,430	869	2,652	450	1,250	1,599	5,332	0	0
79	1,959	7,291	290	1,720	1,119	3,771	550	1,800	1,959	7,291	0	0
1980	2,401	9,692	300	2,020	1,500	5,271	600	2,400	2,400	9,691	1	1
81	3,047	12,739	300	2,320	1,500	6,771	600	3,000	2,400	12,091	647	648
82	3,546	15,285	300	2,620	1,500	8,271	600	3,600	2,400	14,491	1,146	1,794
83	4,118	20,403	300	2,920	1,500	9,771	600	4,200	2,400	16,891	1,718	3,512
84	4,293	24,696	300	3,220	1,500	11,271	600	4,800	2,400	19,291	1,893	5,405
85	4,921	29,617	300	3,520	1,500	12,771	600	5,400	2,400	21,691	2,521	7,926
86	5,468	35,085	300	3,820	1,500	14,271	600	6,000	2,400	24,091	3,068	10,994
87	6,015	41,100	300	4,120	1,500	15,771	600	6,600	2,400	26,491	3,615	14,609

^aThe assignment of loads among the three plants is pure speculation.

^bThe design capacities of the GE, AGNS, and NFS plants are taken as 300, 1500, and 600 tons of fuel per year, respectively.

^cIn May 1973 it is apparent that GE will not process 50 tons of fuel in FY 1973, and probably will process less than 250 tons in FY 1974.

PROJECTIONS OF WASTE SHIPMENTS AND ACCUMULATIONS

Based on an analysis of probable reprocessing flowsheets and waste solidification processes, the final volumes of solidified high-level wastes from reprocessing PWR, HTGR, and LMFBR fuels should be about 2 ft³, 6 ft³, and 3 ft³ per ton of fuel, respectively. Using these estimates of solidified waste volumes, and assuming that all wastes will be stored at the reprocessing plants for 10 years before shipment to a federal repository, Tables 7 through 11 were constructed to depict future annual waste shipments. Table 7 presents the volume of waste shipped, while Tables 8 and 9 present the isotopic power and radioactivity in the wastes that are shipped. The number of waste packages that are shipped annually (Table 10) assumes that the waste is sealed in cylindrical canisters having nominal dimensions of 12 in. in diameter by 10 ft long, and containing 6.28 ft³ of waste, each. The number of annual shipments (Table 11) is based on the assumption that each shipment consists of 12 waste packages.

Properties of the wastes as accumulated at a repository through the year 2010 are given in Table 12.

Table 7. Cubic Feet of Waste Shipped Following 10 Years' Storage

YEAR	PWR-U	PWR-PU	HTGP	AIEC	GFEN	TOTAL
1983	100.0	0.0	0.0	0.0	0.0	100.0
1984	500.0	0.0	0.0	0.0	0.0	500.0
1985	1700.0	0.0	0.0	0.0	0.0	1700.0
1986	2609.5	0.0	0.0	0.0	0.0	2609.5
1987	2555.6	0.0	0.0	0.0	0.0	2555.6
1988	3197.7	0.0	0.0	0.0	0.0	3197.7
1989	3909.4	0.0	23.5	0.0	0.0	3932.9
1990	4251.9	537.8	39.3	0.0	0.0	4829.0
1991	5171.1	906.9	46.1	0.0	0.0	6124.1
1992	5747.0	1270.7	220.6	0.0	0.0	7238.3
1993	6466.5	1636.8	397.9	0.0	0.0	8501.2
1994	6387.1	2002.9	587.0	0.0	0.0	8977.1
1995	7135.1	2369.0	1015.7	0.0	0.0	10519.8
1996	8246.0	2212.1	1435.2	0.0	0.0	11893.4
1997	9542.7	1835.7	1926.6	14.9	0.0	13319.9
1998	11245.7	1464.4	2438.0	21.3	0.0	15169.3
1999	12899.8	1098.3	2952.8	231.3	0.0	17182.2
2000	14568.4	732.2	3537.3	526.2	0.0	19364.1
2001	15949.7	366.1	4100.2	883.5	35.6	21335.1
2002	17999.8	0.0	4583.9	1423.0	53.5	24060.2
2003	19072.4	0.0	5148.5	1412.9	716.4	26350.1
2004	20184.5	0.0	5727.6	1412.3	1701.2	29025.6
2005	20956.2	0.0	6240.8	1412.2	2996.7	31605.9
2006	21742.0	0.0	6694.4	1411.3	4807.8	34656.1
2007	22388.8	0.0	7159.2	1221.8	6845.7	37615.5
2008	21673.8	0.0	7566.4	1140.2	9210.4	39590.7
2009	22359.0	0.0	7997.0	1024.3	11785.7	43165.9
2010	22083.0	0.0	8490.6	885.2	14484.0	45942.8
2011	22847.9	0.0	8929.9	1397.3	17521.7	50696.7
2012	22367.6	0.0	9322.5	1201.9	20511.5	53403.4
2013	22267.3	0.0	9935.9	1133.0	23894.4	57230.6
2014	22720.5	0.0	10392.3	1021.1	27452.1	61586.0
2015	21284.5	0.0	10872.3	683.2	31352.1	64192.1

Table 8. Kilowatts of Waste Thermal Power Shipped Following 10 Years' Storage

YEAR	PWR-U	PWR-PU	HTR	AFC	GEFO	TOTAL
1983	31.7	0.0	0.0	0.0	0.0	31.7
1984	169.3	0.0	0.0	0.0	0.0	169.3
1985	617.9	0.0	0.0	0.0	0.0	617.9
1986	1054.0	0.0	0.0	0.0	0.0	1054.0
1987	1183.7	0.0	0.0	0.0	0.0	1183.7
1988	1533.1	0.0	0.0	0.0	0.0	1533.1
1989	1678.0	0.0	0.0	0.0	0.0	1678.0
1990	2111.3	488.0	0.0	0.0	0.0	2599.4
1991	2548.8	1220.1	0.0	0.0	0.0	3768.9
1992	2900.0	2127.9	17.0	0.0	0.0	5045.8
1993	3239.6	2947.8	52.9	0.0	0.0	6240.3
1994	3292.3	3767.3	113.1	0.0	0.0	7172.7
1995	3643.1	4587.4	229.6	0.0	0.0	8465.1
1996	4263.3	4236.0	390.4	0.0	0.0	8889.8
1997	4816.3	3894.3	603.8	0.0	0.0	9314.4
1998	5692.1	3279.4	866.0	0.0	0.0	9837.5
1999	6605.0	2459.5	1165.1	30.7	0.0	10260.3
2000	7534.3	1639.5	1493.6	105.1	0.0	10772.6
2001	8342.3	819.9	1841.8	210.3	0.0	11214.3
2002	9462.6	0.0	2197.0	354.8	0.0	12014.4
2003	10043.1	0.0	2563.9	438.0	106.2	13151.2
2004	10694.1	0.0	2937.4	438.0	371.8	14441.3
2005	11205.0	0.0	3303.3	438.0	763.0	15714.3
2006	11745.6	0.0	3672.2	438.0	1305.5	17161.4
2007	12231.1	0.0	4025.0	376.7	1933.1	18565.9
2008	11860.5	0.0	4356.8	350.4	2738.3	19306.0
2009	12245.7	0.0	4672.3	315.4	3628.9	20862.3
2010	12106.9	0.0	4981.6	271.6	4565.8	21925.9
2011	12307.5	0.0	5285.8	438.0	5605.4	23636.8
2012	12201.4	0.0	5526.4	376.7	6639.5	24744.0
2013	11911.0	0.0	5834.9	350.4	7923.7	25920.1
2014	12021.4	0.0	6105.8	315.4	9027.8	27470.5
2015	11213.0	0.0	6334.8	210.3	10362.0	28120.0

Table 9. Megacuries Shipped Following 10 Years' Storage

YEAR	PWR-U	PWR-PU	HTGR	AIFC	GEED	TOTAL
1983	9.1	0.0	0.0	0.0	0.0	9.1
1984	48.8	0.0	0.0	0.0	0.0	48.8
1985	178.2	0.0	0.0	0.0	0.0	178.2
1986	304.0	0.0	0.0	0.0	0.0	304.0
1987	341.4	0.0	0.0	0.0	0.0	341.4
1988	442.2	0.0	0.0	0.0	0.0	442.2
1989	541.7	0.0	0.0	0.0	0.0	541.7
1990	609.0	41.9	0.0	0.0	0.0	650.9
1991	735.2	104.7	0.0	0.0	0.0	839.9
1992	836.7	182.6	4.5	0.0	0.0	1023.8
1993	934.4	253.0	13.9	0.0	0.0	1201.3
1994	949.6	323.3	29.7	0.0	0.0	1302.6
1995	1052.3	393.7	60.3	0.0	0.0	1506.2
1996	1229.7	363.5	102.6	0.0	0.0	1695.8
1997	1389.2	334.2	158.6	0.0	0.0	1882.0
1998	1641.8	281.4	227.5	0.0	0.0	2150.7
1999	1905.2	211.1	306.0	10.4	0.0	2432.7
2000	2173.2	140.7	392.3	35.7	0.0	2741.9
2001	2406.3	70.4	483.8	71.3	0.0	3031.8
2002	2729.4	0.0	577.1	120.4	0.0	3426.9
2003	2896.8	0.0	673.5	148.6	34.2	3753.2
2004	3084.6	0.0	771.6	148.6	119.8	4124.6
2005	3232.0	0.0	869.0	148.6	245.9	4495.5
2006	3387.9	0.0	964.6	148.6	420.7	4921.8
2007	3527.0	0.0	1057.3	127.8	622.9	5336.0
2008	3421.1	0.0	1144.4	118.9	882.4	5566.8
2009	3532.2	0.0	1227.3	107.0	1169.4	6035.9
2010	3492.1	0.0	1303.5	92.2	1471.3	6364.1
2011	3550.0	0.0	1383.4	148.6	1806.3	6893.4
2012	3519.4	0.0	1451.6	127.8	2139.5	7238.4
2013	3435.6	0.0	1532.7	118.9	2521.1	7608.4
2014	3467.5	0.0	1603.8	107.0	2909.2	8087.5
2015	3234.3	0.0	1664.0	71.3	3339.1	8308.7

Table 10. Number of Containers Shipped Following 10 Years' Storage

YEAR	PWR-U	PWR-PU	HTGR	AIFC	GEFC	TOTAL
1983	15.9	0.0	0.0	0.0	0.0	15.9
1984	79.6	0.0	0.0	0.0	0.0	79.6
1985	270.7	0.0	0.0	0.0	0.0	270.7
1986	415.6	0.0	0.0	0.0	0.0	415.6
1987	407.0	0.0	0.0	0.0	0.0	407.0
1988	509.2	0.0	0.0	0.0	0.0	509.2
1989	622.6	0.0	3.7	0.0	0.0	626.3
1990	677.1	85.6	6.3	0.0	0.0	769.0
1991	923.5	144.4	7.3	0.0	0.0	975.3
1992	915.2	202.4	35.1	0.0	0.0	1152.7
1993	1029.8	260.7	63.4	0.0	0.0	1353.8
1994	1017.1	319.0	93.5	0.0	0.0	1429.6
1995	1136.3	377.3	161.7	0.0	0.0	1675.3
1996	1313.2	352.3	228.5	0.0	0.0	1894.0
1997	1513.7	292.3	306.8	2.4	0.0	2121.2
1998	1790.9	233.2	388.2	3.4	0.0	2415.7
1999	2054.3	174.9	470.2	36.8	0.0	2736.2
2000	2320.0	116.6	563.3	83.8	0.0	3083.7
2001	2540.0	58.3	652.9	140.7	5.7	3397.5
2002	2866.5	0.0	729.9	226.6	8.5	3831.5
2003	3037.3	0.0	319.8	225.0	114.1	4196.1
2004	3214.4	0.0	912.0	224.9	270.9	4622.2
2005	3337.3	0.0	993.7	224.9	477.2	5033.1
2006	3462.4	0.0	1066.0	224.8	765.6	5518.8
2007	3565.4	0.0	1140.0	194.5	1090.1	5990.0
2008	3451.5	0.0	1204.8	181.6	1466.6	6304.5
2009	3560.7	0.0	1273.4	163.1	1876.7	6873.8
2010	3516.7	0.0	1352.0	140.9	2306.3	7316.0
2011	3639.5	0.0	1421.9	222.5	2790.0	8073.0
2012	3562.0	0.0	1484.5	191.4	3266.1	8504.0
2013	3546.1	0.0	1582.1	180.4	3804.8	9113.4
2014	3618.2	0.0	1654.8	162.6	4371.3	9806.9
2015	3389.6	0.0	1731.2	108.8	4992.3	10221.9

Table 11. Number of Shipments Following 10 Years' Storage

YEAR	PWP-U	PWR-PU	HTGP	AIFC	GEFC	TOTAL
1983	1.3	0.0	0.0	0.0	0.0	1.3
1984	6.6	0.0	0.0	0.0	0.0	6.6
1985	22.6	0.0	0.0	0.0	0.0	22.6
1986	34.6	0.0	0.0	0.0	0.0	34.6
1987	33.9	0.0	0.0	0.0	0.0	33.9
1988	42.4	0.0	0.0	0.0	0.0	42.4
1989	51.9	0.0	0.3	0.0	0.0	52.2
1990	56.4	7.1	0.5	0.0	0.0	64.1
1991	68.6	12.0	0.6	0.0	0.0	81.3
1992	76.3	16.9	2.9	0.0	0.0	96.1
1993	85.8	21.7	5.3	0.0	0.0	112.8
1994	84.8	26.6	7.8	0.0	0.0	119.1
1995	94.7	31.4	13.5	0.0	0.0	139.6
1996	109.4	29.4	19.0	0.0	0.0	157.8
1997	126.6	24.4	25.6	0.2	0.0	176.8
1998	149.2	19.4	32.4	0.3	0.0	201.3
1999	171.2	14.6	39.2	3.1	0.0	228.0
2000	193.3	9.7	46.9	7.0	0.0	257.0
2001	211.7	4.9	54.4	11.7	0.5	283.1
2002	238.9	0.0	60.8	18.9	0.7	319.3
2003	253.1	0.0	68.3	18.7	9.5	349.7
2004	267.8	0.0	76.0	18.7	22.6	385.2
2005	278.1	0.0	82.3	18.7	39.8	419.4
2006	288.5	0.0	88.8	18.7	63.8	459.9
2007	297.1	0.0	95.0	16.2	90.8	499.2
2008	287.6	0.0	100.4	15.1	122.2	525.4
2009	296.7	0.0	106.1	13.6	156.4	572.8
2010	293.0	0.0	112.7	11.7	192.2	609.7
2011	303.2	0.0	118.5	18.5	232.5	672.7
2012	296.8	0.0	123.7	15.9	272.2	708.7
2013	295.5	0.0	131.8	15.0	317.1	759.4
2014	301.5	0.0	137.9	13.5	364.3	817.2
2015	282.4	0.0	144.3	9.1	416.0	851.8

Table 12. Wastes Accumulated at Federal Repository with Shipment After 10 Years' Decay

Fiscal Year	Activity (MCi)		Thermal Power (MW)		Weight of Isotopes (Metric Tons)		Volume of Waste (10 ³ ft ³)	Number of Containers ^c
	Actinides ^a	Fission Products ^b	Actinides ^a	Fission Products ^b	Actinides ^a	Fission Products ^b		
1983	0.065	8.76	0.0019	0.0288	0.159	0.835	0.100	16
84	0.409	55.2	0.012	0.181	1.01	5.32	0.600	96
85	1.66	224	0.048	0.733	4.12	21.7	2.300	366
86	3.76	507	0.111	1.66	9.42	49.5	4.910	782
87	6.05	816	0.178	2.66	15.4	80.8	7.466	1,189
88	8.99	1,217	0.264	3.94	23.1	121	10.66	1,698
89	12.5	1,697	0.369	5.48	32.5	171	14.60	2,324
1990	27.7	2,250	0.868	7.23	44.3	230	19.43	3,093
91	60.2	2,957	1.95	9.55	59.9	306	25.55	4,069
92	113	3,790	3.73	12.2	79.5	397	32.79	5,221
93	185	4,760	6.12	15.3	103	504	41.29	6,575
94	273	5,780	9.09	18.6	129	619	50.27	8,005
95	378	6,940	12.6	22.3	159	757	60.79	9,680
96	474	8,260	15.8	26.5	192	907	72.68	11,574
97	561	9,770	18.7	31.2	228	1,070	86.00	13,695
98	635	11,400	21.1	36.6	267	1,260	101.2	16,111
99	691	13,400	22.9	42.8	311	1,480	118.4	18,847
2000	731	15,500	24.1	49.8	360	1,720	137.7	21,931
01	755	18,000	24.7	57.6	413	1,990	159.0	25,328
02	765	20,700	24.9	66.3	472	2,300	183.1	29,160
03	779	23,700	25.1	75.8	536	2,540	209.5	33,356
04	799	26,900	25.5	86.1	607	3,020	238.5	37,978
05	823	30,400	26.0	97.2	684	3,420	270.1	43,011
06	852	34,200	26.7	109	768	3,370	304.7	48,530
07	887	38,300	27.5	122	859	4,360	342.4	54,520
08	926	42,500	28.4	135	953	4,870	382.0	60,825
09	970	47,000	29.5	149	1,050	5,430	425.1	67,698
2010	1,020	51,700	30.7	164	1,160	6,020	471.1	75,014

^a Assumes 0.5% of the U and Pu in LWR and LMFR fuels, 0.5 % of the U and Th in HTGR fuel, and 100% of the other actinides in the fuels report to waste.

^b Totals include 0.1% of iodine and bromine, and none of the noble-gas and tritium fission products.

^c Containers are 12 in. in diameter by 10 ft long and contain 6.28 ft³ of solidified waste, each.

REFERENCES

1. Nucleonics Week, issues from January 1970 through July 1972.
2. The Growth of Nuclear Power 1972-1985, WASH-1139 (Rev. 1) (December 1971).
3. F. G. Welfare et al., The Oak Ridge Systems Analysis Code (ORSAC) Users' Manual, ORNL-TM-3223 (June 1971).
4. St. George T. Arnold, "Nuclear Industry Growth Projections," paper presented at AECOP Combined Operations Meeting, Oak Ridge, Tennessee, Sept. 26, 1972.
5. W. I. Neef, USAEC Office of Planning and Analysis, communication to J. P. Nichols, ORNL, Sept. 26, 1972.
6. D. E. Deonigi, Battelle Pacific Northwest Laboratories, unpublished mass flow data for light water reactors with Pu recycle (May 1972).
7. L. J. Colby, R. C. Dahlberg, and S. Jaye, HTGR Fuel and Fuel Cycle Summary Description, GA-10233 (May 1971).
8. Keith E. Asmussen, Gulf General Atomic Company, unpublished mass flow data for a reference 1160-MWe HTGR (August 1972).
9. T. D. Wolsko, Argonne National Laboratory, unpublished normalized mass flow data for the A.I. and G.E. Follow-On LMFBR designs (November 1969).

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

INTERNAL DISTRIBUTION

1. R. E. Blanco	19. T. F. Lomenick
2-6. J. O. Blomeke	20. W. C. McClain
7. A. L. Boch	21-25. J. P. Nichols
8. B. F. Bottenfield	26. G. W. Renfro
9. R. D. Cheverton	27. D. B. Trauger
10. H. C. Claiborne	28. Biology Library
11. K. E. Cowser	29-31. Central Research Library
12. F. L. Culler	32. ORNL - Y-12 Technical Library
13. D. E. Ferguson	Document Reference Section
14. F. Gera	33-37. Laboratory Records
15. H. W. Godbee	38. Laboratory Records-RC
16. G. H. Jenks	39. ORNL Patent Office
17. C. W. Kee	40-41. TIC
18. R. E. Leuze	

EXTERNAL DISTRIBUTION

USAEC, Washington, D. C. 20545

42-66. O. P. Gormley

67. W. H. McVey

USAEC-ORO

68. Patent Office

69. J. A. Lenhard

70-74. B. M. Robinson

75. Research and Technical Support Division

OAK RIDGE NATIONAL LABORATORY

OPERATED BY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37830

SPECIAL 4TH CLASS RATE BOOKS

②

*Technical Information Center
Oak Ridge, In*

If a change of address is needed, indicate the change, include the zip code, and identify the document; tear off this cover and return it to the above address.