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**SPENT REACTOR FUEL:
REPROCESSING REQUIREMENT,
ISOTOPE CONTENT AND TRANSPORTATION**

G. L. WILFERT

FEBRUARY 1967

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REPROCESSING REQUIREMENT,
ISOTOPE CONTENT AND TRANSPORTATION

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ABSTRACT

This report estimates the annual rate of spent fuel throughput for each of four sectors of the United States and in addition calculates the associated isotope production for the years 1959 through 1990. Also projected is the annual spent fuel throughput rate for the rest of the free world during 1971, 1976, and 1991. Methods of transporting the spent fuel and the costs of shipping are analyzed. Finally, the impact of sector throughput and transportation to Hanford is reviewed in connection with present commercial reprocessing capabilities.

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SPENT REACTOR FUEL:
REPROCESSING REQUIREMENT,
ISOTOPE CONTENT AND TRANSPORTATION

G. L. Wilfert

INTRODUCTION

Nuclear power reactor installations have shown a growth that was completely unanticipated as recently as 1964. Month after month has seen announcements concerning new reactor projects. So surprising has been this growth that those following the nuclear industry have time and again been forced to revise upward their curves of present and future nuclear growth.

A review of the new nuclear power reactor projects announced for start-up during the years 1969, 1970, and 1971 outlines the immediate growth of the nuclear industry. A summary of nuclear power projects for the U.S. indicates that five new projects with a total of 2,672 MW_e are to be installed in 1969. This does not include the stretch capacity of these reactors, which accounts for an additional 405 MW_e. For 1970 there are nine new nuclear power plants announced which are capable of putting on line an additional 6,343 MW_e. During 1971 the nuclear industry will nearly double its 1970 additions by adding 11,603 MW_e of new nuclear capacity. This 1971 figure includes 405 MW_e of stretch capacity from reactors which initially began operation in 1969. In these calculations the stretch capacity of a nuclear plant has been added two years after initial operation.

What does the recent eruption in proposed nuclear powered electrical generation plants mean to the nuclear industry in terms of the short run and the long? More specifically, what are the short and long term prospects for nuclear growth within various sections of the United States? This study makes an effort to indicate those areas where nuclear growth will take place and attempts to identify both the quantity and the time schedule for each area based on the latest information. (1, 2, 3)

The United States has been divided into four study sectors to facilitate a close inspection of nuclear growth and its impact on the nuclear fuel reprocessing requirements. These four study sectors are referred to throughout the report as the West Sector, the South Sector, the North Central Sector, and the Northeast Sector. These four sectors coincide (Figure 1) with the Federal Power Commission's four sectors as outlined in its 1964 report, "National Power Survey, Outline for Growth of the Electrical Power Industry."

The Federal Power Commission's study of United States electrical power needs is based on studies of 48 power supply areas which cover the adjacent 48 states; it combines these supply areas into 16 coordination areas, which in turn are grouped into eight Federal Power Commission Regions. The eight regions form the four sectors which become the basis for study in this report. The four sectors are the smallest divisions of the United States that can be meaningfully treated in terms of fuel reprocessing requirements at this time because of the size of the present nuclear power reactor industry.

These sector boundaries do not always correspond to state lines, but rather correspond to the boundaries of individual power supply areas. As seen in Figure 1 the Western Sector includes not only the Pacific Coast states but also much of the Rocky Mountain area. The South Sector includes all the south part of the United States from New Mexico to the east. The dividing line between the North Central Sector and the Northeast Sector is Lake Michigan and the state border between Illinois and Indiana.

The nuclear industry analysis began with an estimate of the power requirements in each sector through the year 1990. In many areas nuclear steam generation plants are competing on an economic basis with fossil fuel fired plants. Nuclear growth was calculated on the basis that nuclear powered steam generating plants will continue to be competitive in those areas where fossil fuel costs are medium or high. This is the same assumption that the FPC made in their "National Power Survey" when they projected nuclear growth for each sector.

It is important to realize that the electrical requirements projected for each sector depend on the individual economy of each sector. An

FIGURE 1. U. S. Sector Identification

extended economic abnormality will in the long run be reflected in a sector's electrical demand. For example, the South Sector's electrical requirements have been influenced by NASA's decision to locate many of their facilities in this sector.

The nuclear growth on the national scale has been restricted to the Atomic Energy Commission's latest report⁽¹⁾ on U. S. nuclear growth. This report estimates U. S. nuclear generating capacity to be 99,000 MW_e by the end of 1980 and 310,000 MW_e by 1990. These long term growth estimates are considered conservative but are the best documented growth projections available at the present time.

SUMMARY AND CONCLUSIONS

Today the nuclear industry is in an eruptive state of growth. Newly installed nuclear capacity, for example, will more than double annually during the 4-year period 1968-1971. This tremendous growth will be followed quite closely by a corresponding growth in spent fuel reprocessing requirements.

The present commercial nuclear fuel reprocessing industry has a 1967 capability of reprocessing approximately 450 tons of spent fuel annually. Expectations are that this capacity will be extended to 750 tons annually by late 1970. At the same time the spent fuel throughput from commercial reactors is estimated to be below 50 tons during 1967, but over 1000 tons in 1973.

A minimum spent fuel load for a commercially competitive reprocessing plant has been estimated at 300 tons of throughput per year. If it were assumed that the reprocessing process were comparatively efficient for all reprocessing plants, then the size of the service area for each reprocessing plant would depend heavily upon the transportation cost advantage in its service area.

Table I shows that the Northeast sector is the first to achieve an annual throughput of 300 tons and will do this by 1972. The North Central and South Sectors each approach an annual throughput of 300 tons by 1973. Development of nuclear capacity in the West Sector lags the other sectors by several years and therefore a 300 ton throughput is not approached before 1977.

Throughput for a reprocessing plant located in any one sector may be increased by attracting commercial business from beyond that sector. This not only includes the possibility of attracting spent fuel from other sectors but also of attracting spent fuel from foreign reactors. The Nuclear Fuels Service reprocessing plant located in West Valley, New York, has already announced plans to expand its services to foreign loads. Western Europe may very well be a prime target. Western Europe and those

TABLE IANNUAL DOMESTIC THROUGHPUT OF NUCLEAR FUEL 1959-1990

<u>Year</u>	<u>Metric Tonnes</u>				<u>Total</u>
	<u>West</u>	<u>North Central</u>	<u>South</u>	<u>Northeast</u>	
1959	0	0	0	0	0
1960	0	0	0	0	0
1961	0	0	0	4	4
1962	0	0	0	2	2
1963	0	13	0	14	27
1964	0	26	0	8	34
1965	0	10	0	8	18
1966	4	9	0	16	29
1967	9	9	0	19	37
1968	3	9	0	33	45
1969	33	13	0	55	101
1970	18	19	0	39	76
1971	19	17	0	203	238
1972	51	92	100	297	540
1973	106	278	276	418	1078
1974	100	460	362	484	1406
1975	146	470	387	695	1698
1976	231	384	371	718	1704
1977	281	414	410	795	1900
1978	412	455	469	912	2248
1979	598	503	548	1044	2693
1980	838	550	641	1198	3227
1981	1035	594	817	1498	3944
1982	1254	756	1008	1600	4618
1983	1404	919	1231	1786	5340
1984	1462	1007	1323	1922	5714
1985	1654	1034	1439	2053	6180
1986	1824	1086	1663	2228	6801
1987	1944	1209	1888	2407	7448
1988	2103	1319	2157	2677	8256
1989	2241	1412	2546	2983	9182
1990	2393	1535	2880	3291	10099

countries bordering on the Mediterranean Sea have an estimated annual throughput of over 250 tons annually by 1971 (see Table II). A West Coast reprocessing plant would likely look to Asia and the South Pacific as a potential source of foreign throughput. This area is estimated to have a 100-ton annual spent fuel throughput by 1971.

TABLE II

FOREIGN REACTOR THROUGHPUT OF NUCLEAR FUEL

<u>Area</u>	<u>Metric Tons/Year</u>		
	<u>1971</u>	<u>1976</u>	<u>1991</u>
Asia and South Pacific Area	101.2	343	2221
Canada	40.8	151	1422
Mexico	-0-	16	93
West Europe and Mediterranean Area	264.4	755	5905

DISCUSSION

SURVEY OF NUCLEAR GROWTH

The nuclear industry's growth of large power reactors developed cautiously during the late 50's and early 60's. A survey of commercial power reactors of 50 MW and over shows that the first large commercial reactor was built at Shippingport, Pennsylvania. In 1959 Shippingport came on line with 60 MW_e. The following year, Dresden 1, a 210 MW_e reactor at Morris, Illinois, became operational. In 1963 Big Rock Point and Humboldt Bay started operation. There was a slight pause in reactor completion during 1964 and 1965, but then in 1966 two more reactors began operation. Three reactors are scheduled for operation in 1967 and two more in 1968. The year of 1969 is a year of accelerated nuclear growth, with a total of five reactors providing an electrical capacity of 2,672 MW_e. Although the new additions for 1969 are a large increase over previous years, this same 1969 addition is more than doubled during 1970, when nine reactors are scheduled for operation. The 1970 nuclear additions have a total installed capacity of 6,348 MW_e. Again in 1971 the new installations nearly double that of the previous year, with 14 new reactors scheduled for operation, adding to installed capacity 11,198 MW_e.

It is difficult at this time to determine the new nuclear power capacity that will begin operation during 1972 due to contracts that are still being negotiated for that year. In estimating nuclear growth beyond 1971 the AEC nuclear growth projection provides the information for nuclear forecasts through the year 1990. The AEC forecast estimates nuclear capacity to be 99,000 MW_e in 1980 and 310,000 MW_e by the year 1990. It is interesting to note that the summary of reactor projects ordered for 1971 is above the 19,000 MW_e projected by the AEC for 1972. It becomes necessary to integrate the two projections during the years 1972-1974 to facilitate a smooth transition from the announced short-term to the AEC long-term projection. This transition period eliminates the step function that would occur by switching from the summary of nuclear projects projections for 1971 to the AEC 1972 projection.

Figure 2 combines both short-term and AEC long-term projections to show a single nuclear power reactor growth curve for the years 1960 through 1990. In summary, the nuclear reactor projects were used as a basis for the nuclear power reactor growth curve through the year 1971. From 1972 through 1974, the 1971 projection was phased into the AEC projection. From 1975 through 1990 the AEC nuclear growth projections were used.

Figure 3 locates (by use of a dot map of the United States and Puerto Rico) those reactor sites that have been announced. The dot map allows quick identification of those areas where nuclear power is experiencing success in penetrating the fossil fuel fired steam generation market. The coastal New England area, the Chicago area, and California have developed a nuclear power capacity early.

A summary of the announced nuclear power projects of 50 MW_e, or larger, for each of the four U.S. sectors is given in Table III. When more than one reactor is located at a single site, the individual reactors are further identified by a dash and the number denoting the reactor. For example Dresden-3 is the third reactor to be installed at the Dresden site. Some reactors are recorded as having two power levels, such as Dresden-3 with 753 MW_e and 809 MW_e. The first power level indicated is the initial level. At some later date the initial power level will be stretched to 809 MW_e. The map symbol on Table III is used later to locate the specific reactor site on a U.S. map. The first two numbers of the symbol signify the year the plant began operation. The two Aquirre Stations located in Puerto Rico have been added to the South Sector because it is believed that all fuel fabrication and separation work for this reactor will be done in the U.S. Since Puerto Rico is geographically closer to the South Sector than to any other, the two stations have been treated as though they were located within the boundary of the South Sector.

Specific reactors and their locations are identified for the West, North Central and South Sectors in Figure 4a. The Northeast Sector was broken out separately because of the large number of proposed nuclear reactors for this sector. Also the locations of two commercial reprocessing plants are identified--the General Electric plant in Morris, Illinois (identified in Figure 4a), and the Nuclear Fuels Service plant in West Valley, New York (identified in Figure 4b).

FIGURE 2. Nuclear Power Reactor Growth Curve 1960-1990

FIGURE 3. Locations of Reactor Sites (•) and Reprocessing Plants (X)

TABLE IIISUMMARY OF DOMESTIC NUCLEAR POWER PROJECTS^(a)

<u>Reactor</u>	<u>Location</u>	<u>Power MW_e</u>	<u>Operation Date</u>	<u>Map Symbol^(b)</u>
<u>United States: West Sector</u>				
Humboldt Bay	California	70	1963	63-HB
San Onofre	California	450	1967	67-SO
Malibu	California	490-590	1970	70-MA
Diablo Canyon	California	1060	1971	71-DC
Pelican Point - 1	California	900	1972	72-PP-1
Clay (SMUD)	California	500	1973	73-C
Pelican Point - 2	California	900	1973	73-PP-2
Feather River	California	600	1974	74-FR
<u>United States: North Central Sector</u>				
Dresden - 1	Illinois	210	1961	61-D-1
Pathfinder	South Dakota	60	1966	66-PF
La Crosse	Wisconsin	50	1967	67-LC
Dresden - 2	Illinois	753-809	1969	69-D-2
Dresden - 3	Illinois	753-809	1970	70-D-3
Monticello	Minnesota	393-568	1970	70-MO
Point Beach	Wisconsin	477	1970	70-PB
Quad Cities - 1	Illinois	753-809	1970	70-QC-1
Quad Cities - 2	Illinois	753-809	1971	71-QC-2
Fort Saint Vrain	Colorado	330	1971	71-FSV
Fort Calhoun	Nebraska	472	1971	71-FC
Peru	Nebraska	700	1972	72-PE

(a) Reactors 50 MW_e and larger.

(b) Reactor identification symbol used to locate reactor site on U.S. map.

TABLE III (contd.)

SUMMARY OF DOMESTIC NUCLEAR POWER PROJECTS^(a)

<u>Reactor</u>	<u>Location</u>	<u>Power MW_e -</u>	<u>Operation Date</u>	<u>Map Symbol^(b)</u>
<u>United States: South Sector</u>				
Browns Ferry - 1	Alabama	1100	1970	70-BF-1
Hartsville	South Carolina	760	1970	70-HV
Turkey Point - 3	Florida	728-759	1970	70-TP-3
Browns Ferry - 2	Alabama	1100	1971	71-BF-2
Turkey Point - 4	Florida	728-759	1971	71-TP-4
Oconee - 1	South Carolina	830	1971	71-OE-1
Aguiree Station - 1	Puerto Rico	400	1971	71-AS
Surry Station - 1	Virginia	800	1971	71-SS-1
Aguiree Station - 2	Puerto Rico	400	1972	72-AS
Oconee - 2	South Carolina	830	1972	72-OE-2
Surry Station - 2	Virginia	800	1972	72-SS-2
<u>United States: Northeast Sector</u>				
Shippingport	Pennsylvania	60, + 40	1959, 1964	59-SP
Yankee	Massachusetts	185	1961	61-YA
Big Rock Point	Michigan	75	1963	63-BRP
Indian Point - 1	New York	292	1966	66-IP-1
Connecticut Yankee	Connecticut	490-590	1967	67-CY
Oyster Creek	New Jersey	540-670	1968	68-OC
Nine Mile Point	New York	525-650	1968	68-NMP
Brookwood	New York	435-466	1969	69-BW
Indian Point - 2	New York	906-1020	1969	69-IP-2
Millstone Point	Connecticut	478-682	1969	69-MP
Palisades Park	Michigan	739-845	1970	70-PPK
Boston Edison	Massachusetts	567-641	1971	71-BE
Consolidated Edison	New York	1000	1971	71-CE ^(c)
Delaware Valley - 2	Pennsylvania	1100	1971	71-DVU-2
Vermont Yankee	Vermont	513-540	1971	71-VY
Metropolitan Edison	Pennsylvania	840	1971	71-ME ^(c)
Delaware Valley - 1	New Jersey	1035	1972	72-DVU-1
Main Yankee	Main	700	1972	72-MY
Delaware Valley - 3	New Jersey	1100	1973	73-DVU-3
LILCO Station	New York	500	1973	73-LS
Niagara Mohawk	New York	750	----	----- ^(c)

(a) Reactors 50 MW_e and larger.

(b) Reactor identification symbol used to locate reactor site on U. S. map.

(c) Site selection study underway.

FIGURE 4a. Reactor Identity and Location
(Except Northeast Sector)

Puerto Rico
71-AS
72-AS

FIGURE 4b. Reactor
Identity and Location
(Northeast Sector)

FORECAST BY U. S. SECTOR OF SPENT FUEL THROUGHPUT

The specific breakdown for the amount of nuclear capacity projected for each of the four sectors is noted in Figure 5. The West and the South Sectors show no nuclear power capacity in 1960. The West Sector is expected to have 70,000 MW_e installed nuclear capacity by 1990. The installed capacities in 1990 for the other sectors are: 49,000 MW_e for the North Central Sector, 91,000 MW_e for the South Sector and 100,000 MW_e for the Northeast Sector. These projections of nuclear capacity for each sector become the base upon which sector throughput and isotope production are calculated.

The best estimate for fuel exposure during a typical reactor lifetime is given in Table IV. The Pressurized Water Reactor reaches exposure equilibrium at 27,800 megawatt days per metric ton after the third core. Boiling Water Reactors take longer to reach their exposure equilibrium of 20,000 MWd/MT. Fast reactors discharge a core and a blanket at the same time. Fuel exposure for both the core and blanket at each discharge is also given in Table IV. The discharge schedule for each type of reactor is dependent upon the nuclear reactor load factor. For this study reactors are operated at 85% plant factor for the first 15 years of the reactor's life; then the plant factor is decreased linearly to 50% at the end of 30 years. As shown in Table V the discharge cycle increases after the reactor has operated 15 years.

The nuclear growth within each sector, along with the breakdown of reactor type, power factor and fuel exposure, provides the base for calculating the spent fuel throughput within each sector. It is important to note that the N Reactor located at Hanford, Washington, has not been included in either the summary of reactor projects or the throughput or isotope production calculations for the West Sector. This is because of the uncertainty whether N Reactor will operate on metal or oxide fuels in the future and because of the uncertainty about the fuel exposure level. At a later time when these parameters become more clearly defined, the throughput and isotope production for N Reactor can be added to the West Sector totals.

Exposed fuel is considered throughput at the time it is discharged from the reactor. After the fuel is discharged there is a cooling time from

FIGURE 5. Cumulative Installed Generating Capacity, 1000 MW_e

TABLE IV

STARTUP AND EQUILIBRIUM EXPOSURE VALUES
FOR BOILING WATER, PRESSURIZED WATER, AND FAST REACTORS

<u>Pressurized Water Reactor</u>		<u>Boiling Water Reactor</u>		<u>Fast Reactors</u>		
<u>Discharge</u>	<u>Core Exposure</u>	<u>Discharge</u>	<u>Core Exposure</u>	<u>Discharge</u>	<u>Core Exposure</u>	<u>Blanket Exposure</u>
1	14,400	1	12,700	1	14,000	2,800
2	23,200	2	16,500	2	37,500	4,300
3	28,700	3	15,000	3	57,000	7,000
4	27,800	4	17,100	4	70,000	11,500
5	27,800	5	19,800	5	80,000	11,000
		6	20,500	6	82,000	11,000
		7	19,900	7	82,000	11,000
		8	19,500			
		9	20,000			
		10	20,000			

TABLE V

DISCHARGE SCHEDULE FOR BOILING WATER,
PRESSURIZED WATER, AND FAST REACTORS

<u>Discharge Number</u>	<u>Reactor Age at Time of Discharge, Years</u>		
	<u>PWR</u>	<u>BWR</u>	<u>Fast</u>
1	1.6	2.7	0.4
2	2.5	3.6	1.3
3	3.4	4.5	2.2
4	4.3	5.4	3.3
5	5.2	6.3	4.6
6	6.1	7.1	5.7
7	7.0	8.0	6.7
8	7.9	8.9	7.9
9	8.8	9.8	9.1
10	9.8	10.7	10.2
11	10.7	11.6	
12	11.6	12.5	
13	12.5	13.4	
14	13.4	14.3	
15	14.3	15.2	
16	15.2	16.1	
17	16.1	17.1	
18	17.1	18.1	
19	18.0	19.1	
20	19.0	20.1	
21	20.1	21.1	
22	21.2	22.2	
23	22.3	23.4	
24	23.4	24.6	
25	24.6	25.8	
26	25.6	27.1	
27	27.2	28.5	
28	28.6	29.9	
29	30.0		
30			

90 to 180 days during which time the gamma activity is allowed to diminish by natural decay. It may take one week or longer to ship the reactor throughput to a reprocessing plant. In general there is approximately a 6-month delay between the time a reactor discharges a fuel element and the time the fuel is ready for reprocessing. The annual domestic throughput is calculated at the time of discharge and does not consider the 6-month delay. The annual domestic throughput of nuclear fuel based on the above calculations is presented in Table I for the years 1959 through 1990.

An estimate of the annual production of selected isotopes for the total United States market is summarized in Table VI. Here for the years 1959 through 1990 are listed the annual quantities of plutonium, neptunium-237, americium-241 and -243, curium-242 and -244, promethium-147, cesium-155 and -137, and strontium-90. The national totals are further subdivided on the basis of sector throughput (Tables VIa through VI d). Like throughput, the isotopic concentrations are measured at time of discharge and do not allow for the delay between discharge and the actual time that the isotopes are separated from the fuel.

The minus signs that appear under the plutonium heading after 1980 are the result of fast reactors using plutonium for their initial cores. It is estimated that the amount of plutonium available for fast reactor use will reach a peak of 120 metric tons in 1984. When the estimated fast reactor capacity reaches 14,500 MW_e in 1990, the amount of available plutonium is estimated to decrease to 50 metric tons. Thus, each sector of the U. S. becomes a user of plutonium in the years after 1980.

TABLE VI
ANNUAL DOMESTIC PRODUCTION OF ISOTOPES, kg
(U. S. Total)

<u>Year</u>	<u>Pu</u>	<u>Np-237</u>	<u>Am-241</u>	<u>Am-243</u>	<u>Cm-242</u>	<u>Cm-244</u>	<u>Pm-147</u>	<u>Ce-144</u>	<u>Cs-137</u>	<u>Sr-90</u>
1959	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0
1961	28	1	0	0	0	0	0	1	3	1
1962	17	1	0	0	0	0	0	0	2	1
1963	179	6	1	1	0	0	3	6	18	8
1964	245	9	1	1	0	0	4	8	26	12
1965	137	5	1	1	0	0	2	4	15	7
1966	205	8	1	1	0	0	4	7	22	10
1967	268	10	1	1	0	0	5	9	29	13
1968	328	12	1	1	0	0	6	10	36	16
1969	740	27	3	3	1	1	13	24	80	36
1970	615	26	3	4	1	1	10	18	72	31
1971	1670	59	6	7	1	1	30	55	177	80
1972	3800	134	15	15	4	3	67	126	401	181
1973	7600	268	29	31	7	5	134	251	803	362
1974	10100	368	44	44	10	7	176	329	1080	485
1975	12400	457	58	54	13	9	216	400	1330	598
1976	12700	484	61	59	14	10	219	403	1400	621
1977	14300	552	70	69	16	12	245	450	1590	703
1978	16900	653	83	82	19	14	289	532	1880	831
1979	20200	780	98	97	22	16	346	636	2240	992
1980	24100	926	118	113	26	19	414	763	2660	1180
1981	7550	1110	156	138	31	23	516	950	3210	1430
1982	8420	1280	199	163	36	26	598	1100	3740	1660
1983	10620	1490	253	196	42	31	697	1280	4390	1940
1984	5910	1580	279	209	45	33	744	1370	4670	2070
1985	-510	1710	334	233	48	35	820	1500	5130	2270
1986	-1860	1890	404	264	53	39	919	1680	5750	2550
1987	-3110	2060	479	296	57	42	1020	1860	6380	2830
1988	-6680	2280	566	334	63	46	1140	2080	7150	3170
1989	-6220	2500	665	375	68	50	1260	2310	7950	3520
1990	-12500	2720	778	419	74	54	1390	2550	8780	3900

TABLE VIa
ANNUAL DOMESTIC PRODUCTION OF ISOTOPES, kg
(West Sector)

Year	Pu	Np-237	Am-241	Am-243	Cm-242	Cm-244	Pm-147	Ce-144	Cs-137	Sr-90
1959	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0
1966	25	1	0	0	0	0	0	1	2	1
1967	58	2	0	0	0	0	1	2	6	3
1968	23	1	0	0	0	0	0	1	2	1
1969	231	8	1	1	0	0	4	8	24	11
1970	153	7	1	1	0	0	2	4	19	8
1971	148	7	1	1	0	0	2	4	18	8
1972	378	14	1	2	0	0	7	12	42	18
1973	784	29	3	4	1	1	13	25	86	38
1974	803	34	3	5	1	1	13	24	94	41
1975	1110	44	4	6	1	1	19	34	126	55
1976	1710	65	7	8	2	1	29	64	189	84
1977	2080	79	9	10	2	2	36	66	229	102
1978	3020	113	12	14	3	2	52	97	330	147
1979	4380	164	18	20	4	3	76	140	478	213
1980	6090	226	27	27	6	5	106	197	659	295
1981	502	282	40	35	8	6	139	257	832	372
1982	1870	336	53	43	9	7	163	301	993	442
1983	3210	386	66	51	11	8	184	339	1150	511
1984	3730	411	70	55	12	9	193	354	1220	538
1985	1730	462	87	63	13	10	220	403	1390	613
1986	-451	506	106	71	14	11	245	449	1540	681
1987	782	542	125	78	15	11	264	483	1670	740
1988	-1390	587	144	87	16	12	288	526	1830	809
1989	47	630	165	95	17	13	309	564	1980	877
1990	-2020	665	191	104	18	13	333	608	2140	945

TABLE VIb

ANNUAL DOMESTIC PRODUCTION OF ISOTOPES, kg
(North Central Sector)

<u>Year</u>	<u>Pu</u>	<u>Np-237</u>	<u>Am-241</u>	<u>Am-243</u>	<u>Cm-242</u>	<u>Cm-244</u>	<u>Pm-147</u>	<u>Ce-144</u>	<u>Cs-137</u>	<u>Sr-90</u>
1959	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0
1963	76	2	0	0	0	0	1	3	7	3
1964	174	6	1	1	0	0	3	6	17	8
1965	68	2	0	0	0	0	1	2	7	3
1966	65	3	0	0	0	0	1	2	7	3
1967	67	3	0	0	0	0	1	2	7	3
1968	65	3	0	0	0	0	1	2	7	3
1969	93	3	1	0	0	0	2	3	10	4
1970	133	5	1	0	0	0	2	4	14	6
1971	126	4	1	0	0	0	2	4	13	6
1972	595	19	2	2	0	0	11	21	59	27
1973	1840	59	8	5	2	1	34	64	182	84
1974	3090	101	15	10	3	1	56	107	109	143
1975	3300	113	17	12	3	2	59	110	340	155
1976	2810	104	16	12	3	2	49	91	303	136
1977	3100	117	18	15	4	2	53	98	339	151
1978	3420	130	19	16	4	3	59	108	376	167
1979	3770	145	21	17	4	3	65	120	416	185
1980	4130	159	23	19	5	3	71	131	457	203
1981	4470	173	25	21	5	3	77	141	496	220
1982	1970	213	33	26	6	4	98	181	615	273
1983	-528	251	44	32	7	5	120	222	736	327
1984	205	274	53	35	8	5	133	245	818	363
1985	-3230	276	59	37	8	5	138	254	836	371
1986	-2660	293	68	41	8	6	147	270	899	398
1987	-5199	319	84	47	9	6	165	303	1010	446
1988	-7870	341	101	52	9	7	182	334	1100	489
1989	-6780	363	121	58	10	7	198	362	1210	537
1990	-9210	389	142	65	10	7	217	397	1330	590

TABLE VIc
ANNUAL DOMESTIC PRODUCTION OF ISOTOPES, kg
(South Sector)

Year	Pu	Np-237	Am-241	Am-243	Cm-242	Cm-244	Pm-147	Ce-144	Cs-137	Sr-90
1959	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0
1972	692	23	2	3	1	0	12	23	72	32
1973	1930	67	6	8	2	1	34	64	203	91
1974	2620	97	11	12	3	2	46	85	283	126
1975	2850	107	13	13	3	2	49	91	310	139
1976	2800	109	13	14	3	2	48	88	313	138
1977	3130	123	15	16	4	3	53	97	352	155
1978	3570	141	17	18	4	3	61	111	401	177
1979	4150	163	20	20	5	3	71	130	465	205
1980	4840	189	23	24	5	4	83	152	541	239
1981	-1310	223	33	28	6	5	106	195	651	289
1982	183	279	45	37	8	6	132	243	822	364
1983	1990	344	61	46	10	7	163	299	1020	453
1984	-1310	352	66	47	10	7	171	314	1050	467
1985	-266	381	79	53	11	8	187	342	1160	515
1986	-1940	439	100	63	12	9	220	403	1360	605
1987	-3370	507	122	74	14	10	258	475	1590	707
1988	-420	598	151	88	16	12	306	563	1900	846
1989	-1170	688	180	102	18	14	354	652	2200	980
1990	-1730	782	214	118	21	15	405	745	2520	1120

TABLE VI d

ANNUAL DOMESTIC PRODUCTION OF ISOTOPES, kg
(Northeast Sector)

<u>Year</u>	<u>Pu</u>	<u>Np-237</u>	<u>Am-241</u>	<u>Am-243</u>	<u>Cm-242</u>	<u>Cm-244</u>	<u>Pm-147</u>	<u>Ce-144</u>	<u>Cs-137</u>	<u>Sr-90</u>
1959	0	0	0	0	0	0	0	0	0	0
1960	0	0	0	0	0	0	0	0	0	0
1961	28	1	0	0	0	0	0	1	3	1
1962	17	1	0	0	0	0	0	0	2	1
1963	103	4	0	0	0	0	2	3	11	5
1964	71	3	0	1	0	0	1	2	9	4
1965	69	3	0	0	0	0	1	2	8	4
1966	115	4	0	1	0	0	2	4	13	6
1967	143	6	1	1	0	0	2	4	16	7
1968	240	9	1	1	0	0	4	8	26	12
1969	416	16	1	2	0	0	7	13	46	20
1970	329	15	1	2	0	0	5	9	40	17
1971	1390	48	5	5	1	1	25	47	145	66
1972	2140	78	9	9	2	2	37	70	229	103
1973	3050	113	12	14	3	2	53	98	331	148
1974	3570	136	15	17	4	3	61	113	394	175
1975	5110	192	24	23	5	4	88	164	556	248
1976	5350	204	25	25	6	5	92	171	591	263
1977	5980	233	29	29	7	5	102	188	666	295
1978	6910	269	33	34	8	6	118	216	771	341
1979	7900	309	38	39	9	7	135	248	883	391
1980	9040	352	44	44	10	7	155	284	1010	446
1981	3900	430	59	54	12	9	195	357	1240	548
1982	4700	458	69	59	13	10	209	385	1330	588
1983	6320	520	83	69	15	11	236	432	1520	670
1984	3660	555	92	73	16	12	254	466	1620	716
1985	1190	586	109	80	17	12	274	502	1740	768
1986	2800	635	129	89	18	13	300	548	1910	846
1987	4410	685	147	97	19	14	325	594	2090	922
1988	3040	754	169	108	21	15	362	663	2320	1026
1989	2030	829	200	121	23	17	406	743	2590	1146
1990	1100	905	234	135	25	18	450	824	2870	1270

THE INTERNATIONAL OUTLOOK FOR SPENT FUEL

For several years both governmental agencies and independent firms have been investigating the international nuclear power market. Such reports as H. B. Merlin's "World Forecast of Nuclear Capacity to 1985,"⁽⁴⁾ have been used as basic information for forecasting the free world's throughput.

The free world, excluding the U. S. and Puerto Rico, is divided into four areas, depending on the shipping distance to the United States. Canada and Mexico are treated as independent countries because they both border on the U. S. and could ship spent fuel by rail. Asia and the South Pacific include the nations of potential nuclear growth of Japan, India, Taiwan, Pakistan, Philippines, Malaya, and New Zealand. These countries have a closer contact with the West Sector of the U. S. (through shipping) than with any other U. S. sector. The Western Europe and Mediterranean nations include Israel, United Arab Republic, Belgium, France, West Germany, Italy, Netherlands, United Kingdom, Spain, Portugal, Sweden, Finland, Denmark, and Switzerland. This market area has its closest link with the Northeastern and South Sectors of the United States through direct shipping connections.

The nuclear projects in each of the four areas of the world are summarized in Table VII. The basis for forecasting the nuclear growth for each country is given in the latest published estimates of foreign nuclear capacity.⁽³⁻⁸⁾ Throughout Asia and the South Pacific Area it is assumed that future reactors constructed through 1990 would be evenly divided between boiling water reactors and pressurized water reactors.

For Israel, UAR, West Germany, Italy, Belgium, Netherlands, Spain, Portugal, Finland, Denmark, and Switzerland, it is estimated that 25% of the new nuclear power reactors constructed through 1990 will be boiling water reactors, 25% will be pressurized water reactors and the remaining 50% will be gas-cooled reactors. France and the United Kingdom are heavily committed to gas-cooled reactors through 1975. It is estimated that from 1975 through 1990 these two countries will construct 50% gas-cooled reactors and 50% breeders.

TABLE VIISUMMARY OF FOREIGN NUCLEAR POWER PROJECTS^(a)

<u>Reactor</u>	<u>Location</u>	<u>Power, MW_e</u>	<u>Operation Date</u>
<u>Asia and the South Pacific</u>			
Tokai-Station	Japan	150	1965
Tarapur - 1	India	190	1968
Tarapur - 2	India	190	1968
KANUPP	Pakistan	132	1968
RAPP	India	200	1969
Tsuruga-Japco	Japan	310	1970
Mihama Station	Japan	325	1970
Fukushima Station	Japan	440	1971
Chugoku Electric	Japan	350	1974-75
Kyushu Electric	Japan	350	----
Chubu Electric	Japan	300	----
Shikoku Electric	Japan	---	----
Kalpakkam	India	---	----
<u>Mexico</u>			
Texcoco Station	Lake Texcoco	500	1975
<u>Canada</u>			
CANDU	Ontario	203	1966
Pickering - 1	Ontario	1000	1970
Pickering - 2	Ontario	1000	1971
CANDU-BLW	Quebec	250	1971

^(a) Reactors 50 MW_e and larger.

TABLE VII (contd.)

SUMMARY OF FOREIGN NUCLEAR POWER PROJECTS

<u>Reactor</u>	<u>Location</u>	<u>Power, MW_e</u>	<u>Operation Date</u>
<u>Western Europe and Mediterrean Area</u>			
EDF - 1	France	68	1959
Berkeley	Britain	276	1962
Bradwell	Britain	300	1962
Garigliano	Italy	150	1963
Latina	Italy	200	1963
Enrico Fermi	Italy	290	1964
EDF - 2	France	195	1964
Hinkley Point - A	England	500	1964
Hunterston - A	England	300	1964
Trawsfynydd	Wales	500	1965
Dungeness - A	England	550	1965
MZFR	West Germany	50	1966
EDF - 3	France	480	1966
Sizewell	England	580	1966
Oldbury - 1	England	280	1966
KRB Station	West Germany	237	1967
EL - 4	France	70	1967
Franco-Belge Ardennes	France	288	1967
Oldbury - 2	England	280	1967
SGHWR	England	90	1967
Dodewaard	Netherlands	50	1968
Marviken	Sweden	200	1968
Lingen Station	West Germany	240	1968
Obrigheim Station	West Germany	283	1968
Zorita	Spain	153	1968
EDF - 4	France	500	1968
NOK Reactor	Switzerland	350	1969
Wylfa	Wales	1180	1969
Oskarshamn	Sweden	400	1970
KKN Station	West Germany	100	1970
Santa Maria De Garona	Spain	440	1970

(a) Reactors 50 MW_e and larger.

TABLE VII (contd.)

SUMMARY OF FOREIGN NUCLEAR POWER PROJECTS

<u>Reactor</u>	<u>Location</u>	<u>Power, MW_e</u>	<u>Operation Date</u>
<u>Western Europe and Mediterrean Area</u>			
Saint Laurent Des Eaux - 2	France	500	1970
EDF - 5	France	500	1970
Dungeness - B	England	1200	1970
Finland Station	Finland	400	1970
Catalonia Station	Spain	500	1971
ENEL Station	Italy	700	1971
Muehleberg Station	Switzerland	300	1971
PFR	Scotland	250	1971
Flanders Station	Belgium	600	1971
Motor-Columbus	Switzerland	500	1972
Intercom Station	Belgium	600	1972
Prototype Fast Reactor	West Germany	300	1973
NOK Station - 2	Switzerland	---	----
Bellinzona Station	Switzerland	125	----
Phenix	France	185	----
Hinkley Point - 2	England	1200	----
UAR	UAR	150	----

(a) Reactors 50 MW_e and larger.

Switzerland so far has strongly backed heavy water reactors. Therefore, all reactors constructed in Switzerland through 1990 are assumed to be of the heavy water type.

In Canada, future nuclear construction is assumed to be 100% heavy water reactors, and in Mexico nuclear growth is divided evenly between boiling water and pressurized water reactors.

COMMERCIAL REPROCESSING CAPABILITY IN THE UNITED STATES

Spent fuel reprocessing is one nuclear area being watched closely by several companies considering the nuclear fuel business. Three of these are Nuclear Fuels Service, General Electric, and Allied Chemical. They see the market for spent fuel reprocessing growing very rapidly after 1970. Nuclear Service, for example, views the industrial market at 1385 tons by 1975 and 3080 tons by 1980.⁽⁹⁾ These figures are slightly lower than the throughputs calculated during this study. Table I shows that the current estimates are 1700 tons of spent fuel throughput in 1975 and 3230 tons in 1980.

The Nuclear Fuel Service reprocessing plant near West Valley, New York, was the first large capacity plant to go into service in the United States. It is capable of handling 450 tons of low enriched fuels per year.⁽⁹⁾ To support this facility during the early years of operation, NFS and the AEC have signed an agreement in which the AEC agrees to provide a base workload of approximately 625 days of operating time from 1966 through the next 5 years. Above this base load NFS has announced that it is looking to foreign sources for loads to keep the plant busy over the next 5 years.⁽¹⁰⁾

NFS has experienced some difficulty in shipping fuel elements from reactor site to their reprocessing plant. The New York Central has refused to handle Yankee spent fuel traffic in the absence of legislation to provide railroads with full insurance and indemnity protection from radioactive risk and liability. A contract involving five railroads has been signed which will allow shipment of spent fuel to NFS by a circuitous route. A Westinghouse cask containing ten fuel elements leaves the Yankee reactor site every other Thursday and the empty cask is returned every other Monday. At present Dresden-1 is also shipping spent fuels to NFS, using a Stan-Ray cask on the basis of three round trips per month. The cask handles a maximum of 24 assemblies per shipment.

General Electric in September 1966 announced that it will locate the nation's second privately financed spent fuel processing plant at Morris,

Illinois. General Electric first considered constructing a reprocessing plant at a West Coast location, but since that time several changes in reactor construction have been announced. Pacific Gas and Electric's Bodega Bay project has been dropped. On the other hand, Commonwealth Edison, builder of the 210 MW_e Dresden-1 station, has ordered four 890 MW_e plants, two more for the Dresden site and two to be located near Cordova, Illinois. Northern States Power Company has also purchased a General Electric reactor of 545 MW_e capacity to be installed at Monticello, Minnesota.

Other reactors planned for the North Central Sector include those for the Wisconsin-Michigan Power Company at Twin Creeks, Wisconsin, and for Consumer's Power Company at Palisades, Michigan. Newly completed light water reactors in the area include Elk River, Big Rock Point, and La Crosse. By 1973 the total light water reactor load in the North Central Sector is expected to generate an annual throughput of 278 tons.

General Electric has announced that its reprocessing plant will be able to offer fuel recovery services to nuclear power plants operating anywhere in the nation. The plant has been designed to process 300 tons/year and has a target operation date in early 1970. At present the recovery plant does not have a definite contract or understanding with any North Central utilities for reprocessing fuels.⁽¹¹⁾ However, a G.E. contract with the TVA for twin 1100 MW_e reactors at Browns Ferry, Alabama, provides for G.E. to have the responsibility for reprocessing fuels during the 12-year period in which G.E. is guaranteeing power generation.

Allied Chemical is reportedly pushing ahead with its plans to get into fuel reprocessing,⁽¹²⁾ and has had Bechtel Corporation do an engineering evaluation of specific processes. About a year ago Allied Chemical dropped its plans for a pilot plant for the Aqua Flor process and switched to the Fluoride Volatility process. A spokesman for the Company has stated that Allied Chemical certainly will get into the reprocessing business and when it does its initial pilot plant will be west of the Mississippi. Allied Chemical has stressed that it is interested only in reprocessing low enrichment fuels.

TRANSPORTATION OF SPENT FUEL

Spent fuels, because of their high gamma activity, require special transportation facilities when being moved from the reactor site to a reprocessing plant. To limit the gamma activity, a heavy shielding, most often in the form of a cylinder, is used. These heavily shielded "casks" as they are called may be transported by either truck, railroad or barge. The particular method of transporting the cask is likely dictated by an economic evaluation of minimum cost. A close look at each method reveals some interesting points.

1. Truck

Motor truck facilities are currently being utilized for transporting small casks. Most of these casks are averaging 25,000 pounds but it is believed that this could be raised to 40,000 pounds. Assuming that the load maximums were lifted to 40,000 pounds, motor truck shipments between two points such as Portland and Hanford would still cost more than by rail. This seems unrealistic and would probably be justification for a reduced rate.

Complicating motor truck shipments are the release charges associated with a cargo value. Motor shipment costs increase substantially as the cargo value rises. Between Portland and Hanford, for example, the hundred weight rate is \$1.12 for a release rate of \$0.40 per pound, \$1.57 for a release value between \$0.40 and \$1.00, and \$2.25 for a release value of \$1.00 and over. Since the original cost of the cask itself is about \$1.25 per pound, this would indicate a rate of \$2.25 per hundredweight. It is expected that casks will be used for a period of 5 to 10 years, and the shipping value utilized would be closer to \$0.40 than to \$1.00 over this period of time.

When loaded with nuclear fuels the cask would have to move at the rate of \$2.25 per hundredweight since the value per pound would greatly exceed the dollar minimum set up in the rate. At this stage, truck rates are not very competitive with rail but if sizeable loads did develop they would probably be reduced. As a general rule where alternative transportation services are available their separate rates tend to be in close accord

(for example, grain movements by rail and motor from Pasco to Portland and Seattle).

2. Railroad

Tables VIII and IX present rail rates per hundredweight for a number of cities throughout the nation. Table IX relates specifically to class rates for cask movement both loaded and unloaded between Hanford and selected cities. Loaded casks are based on Class 40 rates while unloaded movements are assigned to Class 35. The rates shown in Table IX are typical for infrequent shipments. As these volumes develop and the movement becomes more regular, it is usual for the rails and ships to negotiate a commodity rate. As an example note the NFS-Hanford negotiated rate of \$3.68. Under the class structure and assuming New York-Boston figures, the existing class rate would have been \$4.02. These Hanford-NFS shipments are currently being made under Section 22 of the Transportation Act.

Costs of the NFS-Hanford shipments approximate \$20,000 per round trip. In the earlier stages, escort services had to be provided, but currently these extra costs have been eliminated. The cost breakdown is:

Shipping Cost (loaded cask)	\$6,110
Shipping Cost (unloaded cask)	4,680
Fuel Loading	6,120
Fuel Unloading	3,500

Hanford loading costs are probably more than average, since the fuel elements are small.

Table VIII presents a comparison of Hanford rates with those likely to be associated with the Morris, Illinois reprocessing operation, through which we can compare the costs for empty cask movements. Only the city of Detroit is included in both of these data series but the other cities shown are close enough to generally indicate the rate patterns for their areas, and can be used as a comparison. For example, Peekskill, New York, is about as far away as New York City. Homestead, Florida, is much farther than Jacksonville, Florida, and should reflect this in its rate comparison.

TABLE VIII
 COMPARISON OF RAIL RATES
 TO HANFORD, WASHINGTON AND MORRIS, ILLINOIS
 (In Dollars per Hundredweight)

<u>From</u>	<u>Morris</u>	<u>Hanford</u>
Burlington, New Jersey	1.68	
Ontario Center, New York	1.36	
Peekskill, New York	1.73	
New York, New York		3.51
Cobalt, Connecticut	1.75	
Rowe, Massachusetts	1.68	
Boston, Massachusetts		3.51
Reading, Pennsylvania	1.60	
Parr, South Carolina	1.62	
Hartsville, South Carolina	1.75	
Oakridge, Tennessee		3.22
Homestead, Florida	2.28	
Jacksonville, Florida		3.51
Chicago, Illinois		2.93
Cincinnati, Ohio		3.07
Detroit, Michigan	0.97	3.07
San Onofre, California	3.56	
Los Angeles, California		2.34
San Diego, California		2.51

TABLE IX

RAIL RATES TO HANFORD FROM POINTS WITHIN EACH SECTOR

Fuel Casks Loaded and Unloaded*
(Class 35 and 40)

<u>To Hanford From:</u>	<u>Loaded**</u>	<u>Unloaded**</u>
<u>West Sector</u>		
Seattle, Washington	0.95	0.84
Portland, Oregon	1.12	0.98
Scoville, Idaho	0.70***	0.50***
Idaho Falls, Idaho	1.72	1.51
San Francisco, California	2.05	1.80
Los Angeles, California	2.68	2.34
San Diego, California	2.86	
Phoenix, Arizona	3.09	2.71
<u>North Central Sector</u>		
Minneapolis, Minnesota	3.01	2.64
Chicago, Illinois	3.34	2.93
Detroit, Michigan	3.51	3.07
Cincinnati, Ohio	2.51	3.07
<u>South Sector</u>		
Memphis, Tennessee	3.34	2.93
Jacksonville, Florida	4.02	3.51
Oak Ridge, Tennessee	3.68	3.22
<u>Northeastern Sector</u>		
New York, New York	4.02	3.51
Boston, Massachusetts	4.02	3.51
NFS	3.68	3.45

*Minimum weight of 200,000 pounds.

**Freight rate in dollars per hundredweight.

***Range from 1.30 for 30,000 pounds to 0.70 for 200,000 pounds.

San Onofre lies between Los Angeles and San Diego and could be roughly assumed to be comparable with those locations.

For the eastern cities Morris has an obvious advantage. The rate from Morris to Peekskill, New York, is only \$1.73 as compared with \$3.51 from Hanford to New York. Florida cities would certainly be in the Morris territory since the rate from Morris to Homestead is only \$2.28 as compared with a rate from Hanford to Jacksonville of \$3.51.

Table X presents anticipated cask shipment costs for a 100 ton cask loaded with 10 tons of fuel on a round trip from each of the four U.S. sectors.

TABLE X
ANTICIPATED CASK SHIPMENT COSTS*

<u>Shipments Between Hanford and:</u>	<u>Round Trip Cost</u>
<u>West Sector</u>	
Seattle, Washington	\$ 3,770
Portland, Oregon	4,424
Scoville, Idaho	3,800
Idaho Falls, Idaho	6,800
San Francisco, California	8,110
Los Angeles, California	10,576
San Diego, California	11,312
<u>North Central Sector</u>	
Minneapolis, Minnesota	11,902
Chicago, Illinois	13,208
Cincinnati, Ohio	13,862
<u>South Sector</u>	
Oak Ridge, Tennessee	14,536
Jacksonville, Florida	15,846
<u>Northeastern Sector</u>	
New York, New York	15,846
Boston, Massachusetts	15,846

*Round trip per 100 ton cask plus 10 ton fuel.

As a general observation it appears that a rail transportation cost break point would extend southward through the Western Dakotas, coming close to Denver and verging slightly westward to the nation's borders (see Figure 6).

3. Barge

Inland Water Transportation

Currently the Portland-Hanford barge rate for fuel cask movements is quoted at \$6.65 per ton for a 500-ton minimum. This rate includes a towing charge of approximately \$30.00 per hour along with the usage of a single barge for the purpose. No other items would move with this shipment and there may be additional costs in securing the cask. The barge company assumes that it would require 36 hours from Portland to Pasco, with another 8 to 10 hours between Pasco and the Hanford site. Under this current rate structure an average cost of barge movement of a 100-ton cask from Portland to Hanford and return would be computed at 500 tons x \$6.65 x 2, or a total of \$6,650. This would be about \$2,200 more than the direct rail transportation cost and furthermore rail transportation could move the casks directly to the reprocessing plant without requiring intermediate reloading.

The \$2,200 figure can be considered unfair to the assessment of barge feasibility in view of the new rates which will be made effective on availability of slack water behind the John Day Dam and the possibility that cask movements would be considered more than infrequent affairs. Barge operators would give no official estimates, but generally they feel that with a minimum of 10 movements a year, plus the general reduction in rates expected in 1968, the present water transportation cost could be dropped to about half of its present figure, and the minimum load could be reduced to only 200 tons. This new cost would be about 25% less than the current railroad cost.

In addition to the dollar cost of barge movements themselves, the lift off at a Hanford site and rail movement over the seven miles between

FIGURE 6. Railroad Freight Cost Advantage Boundaries Between Hanford, Washington and Morris, Illinois

dock terminal and reprocessing plant poses problems. In view of the high cost of a rail spur and the capital investment of \$200,000 required for crane facilities for the terminal lift off, the prospect for on-site barge lift off is unlikely. It might be more feasible to lift off the cask at one of the Tri-City ports for transfer to the Hanford railway system or to transfer the fuel elements from the large cask to smaller casks. All three ports would be interested in performing this service and in providing the crane facilities for it. Richland was especially interested, and willing to discuss the possibility in further detail.

Ocean Transportation

Reprocessing economics for a West Coast processing plant indicate that the volume of spent fuel in the West Sector will not be large enough for economic operation until after 1975. To increase the volume it becomes important to look at potential sources of reprocessing volume outside the Western Sector. One suggestion is that Hanford should become sufficiently competitive to attract commercial fuels from other sectors of the U.S. This indicates that Hanford would require a definite processing advantage over other reprocessing plants located in other sectors in order to overcome the transportation disadvantage (estimated at \$2 per hundredweight for a typical Central U.S. reactor).

In addition to competing for movement of spent fuel from the North Central and South Sectors, it is also suggested that spent fuel from Asian reactors be seriously considered for increasing the initial processing volume. The volume of Asian spent fuel is estimated to reach over 100 tons annually by the end of 1971 and increase to 340 tons annually by 1976. Capture of this Asian reprocessing could mean that the combination of West Sector and Asian spent fuel volume could well exceed 300 tons annually by 1976.

To this end the prospects for water transportation of Asian spent fuel have been reviewed in some detail. At first glance Asia-U.S. water transportation costs appear to be tremendously high. In addition to high dollar costs the supporting services necessary to move spent fuel casks are

not fully available either for barge or ship haul. At least two recent movements (by mid-year 1966) have been reported of Japanese based fuels moved through the port of Seattle to Idaho Falls. These movements have involved a combination of water and rail transfers.

The most dramatic development which could influence cask movements from Asian ports relates to the newly conceived lighter ships. These ships are designed to carry several 400-ton barges which could be loaded rapidly and could be lifted off at a variety of points along the ship's scheduled runs.⁽¹³⁾ The barges could readily be towed up the Columbia River to the Tri-Cities. Spent fuel shipments from California reactors could be similarly moved.

Transportation costs for movement of Asian fuel to the United States are presently high, a shipment of a 107-ton cask costs approximately \$43,000 per round trip between Tokyo and West Coast points. Table XI shows these charges in detail and compares total cost for ocean and rail movement to both Hanford, Washington, and Morris, Illinois. The table shows that it costs approximately \$10,000 more to move a typical load from Tokyo to Morris than to Hanford.

TABLE XI

FUEL TRANSPORTATION COSTS FOR ASIAN FUELS

Japan to Hanford, Washington-Morris, Illinois
 (200,000 pound cask, 14,000 pound fuel load)

Ocean Rate

Japan to
 Seattle/Portland

Loaded \$330.00/ton x 107 = \$35,310.00

Empty \$55.00 x 100 = 5,500.00

Lift off empty 870.00

Lift off loaded 874.00

Total	\$42,554.00	\$42,554.00	\$42,554.00
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Rail Rate

Portland to Hanford 4,357.00

Seattle to Hanford 3,718.00

Seattle/Portland to Morris 14,750.00

Total Shipping Cost Japan to

Hanford via Portland 46,911.00

Hanford via Seattle 46,272.00

Morris via Seattle/Portland 57,304.00

UNIT SHIPPING COSTS

The transportation rate is only one of many factors that determine the final per unit cost of shipping spent fuel from a reactor site to a reprocessing plant. Two other very important factors are the cooling time and the weight of proper shielding. Shipping costs are expressed in the study in dollars per kilogram of reference material charged at the reactor. For uranium-based fuels, the usual reference material is total uranium.

As shown in Figure 7, for a General Electric 1000 MW_e reactor the total per unit shipping costs tend to decrease as the number of elements per cask is increased. The size of the cask and therefore the number of fuel elements in a cask is limited by weight restrictions. If this limit did not exist the per unit cost would continue to decrease as the number of fuel elements increases. Sixty-four fuel elements would have a combined cask and spent fuel weight of over 175 tons. This is 50 tons above the capacity of modern railroad cars. ⁽¹⁴⁾

Figure 8 shows the effect of cooling time on shipping cost for the General Electric 1000 MW_e reactor. As cooling time is increased, transportation costs go down because more spent fuel elements can be shipped in a cask of a given loaded weight. Inventory charges during the cooling period increase. The total cost, which is the sum of these, is minimized for a cooling time of 120 days. The curve shown is for a burnup of 22,000 MWd/ton and a specific power of 15.4 MW/MT. At other values of burnup and specific power, the optional cooling time could be different.

Appendix A goes into considerable detail concerning the shipping costs as they vary according to reactor size and type. A total of six specific reactors are studied to determine shipping costs.

FIGURE 7

Cost of Shipping Spent Fuel From a G. E. 1000 MW_e Reactor
(Located at Los Angeles, California)

FIGURE 8

Cost of Shipment Versus Cooling Time

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APPENDIX ASpent Fuel Shipment Costs

Spent fuels removed from a reactor are normally cooled from 90 to 180 days before shipment to allow the gamma activity and heat generation rate to diminish to a more easily handled level. One of the sources of high-energy gamma is iodine-131, which has an eight day half-life. In 160 days I-131 will have decayed to less than a millionth of its initial value. For spent fuel processed much before 160 days special reprocessing equipment is required to handle I-131. As a result a reprocessing plant may not desire the spent fuel to arrive much before 160 days after discharge. I-131 is also to be considered when evaluating a shipping accident where cask and fuel elements are ruptured in a way that I-131 would escape into the atmosphere.

Shipments of spent fuel from the reactor to the reprocessing plant are made in heavily shielded casks. A major portion of the shipping costs, therefore, can be attributed to the weight of the cask. It is important that cask design calculations be approximated before the shipping costs are estimated. Once the cask has been designed, the major shipping costs to be considered are the following: a) container cost, b) freight cost, c) handling cost, and d) insurance cost.

Container cost in dollars per pound of cask weight varies widely. Lead shielded casks have been purchased at prices ranging from less than \$1.00 to more than \$3/lb of cask weight. A 70 ton lead shielded steel cask without a cooling system might be expected to cost about \$1.25/lb today, using carbon steel shells.⁽¹⁴⁾ If several identical casks are purchased, the cost per pound is reduced. In this study, the cost per pound has been set at \$1.25. It was decided early in the study to design an uncooled cask; one that is air filled, and cooled only by natural radiation and convection to the outside air. The amortization period chosen was 7 years, which establishes an annual fixed charge rate of 14.29 percent. Estimated freight rates for rail travel between Hanford and

Los Angeles, California are listed in Table IX, page 36. Round trip shipping time for this distance is 16 days. The rail rate and round trip shipping times are constant for each reactor (Table A-I), with rail rates based on carload shipments. Rates for less than carload lots would be higher.

The following approximate relationships were used for the total round trip handling costs:⁽¹⁴⁾

$$Ch = 300 + 4(N + W)$$

where

Ch = handling cost, dollars per round trip

N = number of fuel elements per cask

W = weight of loaded cask, tons..

This relationship gives some weight to factors that influence handling costs, and is therefore believed preferable to the use of constant rates such as \$500/round trip.

Little information is available on insurance rates to cover shipment damage to irradiated fuels. Rates for fresh fuels have been estimated at approximately 0.0005 times the value of the shipment.⁽¹⁴⁾ Total insurance was calculated at 0.0005 times the value of the cask and its contents on each portion of the round trip.

It was assumed that the fuel is leased from the Atomic Energy Commission with a charge rate of 4.75 percent per year based on fuel value. Inventory charges are important when minimizing total transportation costs. As the spent fuel cooling time increases, the total inventory charge increases, but shipping costs diminish because a greater number of fuel elements can be shipped in a cask of a given design. To optimize the overall system, the sum of the shipping cost and the cooling cost must be minimized.

In order to study transportation costs in detail six reactors have been analyzed because of their size and type. Each of the six is important because it is either constructed, being constructed, or has been proposed

TABLE A-I

REACTOR AND SHIPPING CASK INFORMATION

	<u>Dresden-1</u>	<u>Yankee</u>	<u>Dresden-2</u>	<u>Connecticut Yankee</u>	<u>General Electric 1000 MW_e</u>	<u>Indian Point-2</u>
Reactor						
Power, MW _{th}	700	482	2255	1473	3194	2758
Burnup, MWd/metric ton ref. mat.	11500	12500	15000	21800	22000	27000
Specific power, MW/metric ton ref. mat.	11.60	30.0	15.9	21.7	15.4	32.0
Load factor	0.80	0.80	0.80	0.80	0.80	0.80
Fuel Element						
Length, overall, ft	11.17	9.3	14.0	12.0	14.0	14.0
Length, active, ft	9.33	7.5	12.0	10.0	12.0	12.0
Weight, lb/ft	33.4	101.0	41.1	134.6	39.4	112.0
Surface area, ft ²	52.5	217.0	87.74	291.0	62.7	271.0
Kilograms ref. mat. per element	110.0	281.0	199.5	302.0	136.1	422.0
Number of pins per element	36	306	49	225	36	204
Pin outside diameter, in.	0.57	0.34	0.57	0.4115	0.555	0.422
Pin spacing, centers, in.	0.706	0.42	0.728	0.553	0.706	0.556
Dose						
Maximum allowable, mr/hr	10.0	10.0	10.0	10.0	10.0	10.0
At distance from surface, in.	39.37	39.37	39.37	39.37	39.37	39.37
Time per trip per cask, days	16	16	16	16	16	16
Freight rate, empty, \$/lb	0.0234	0.0234	0.0234	0.0234	0.0234	0.0234
Freight rate, loaded, \$/lb	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268
Insurance rate, fraction of value	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Fuel value, \$/kg ref. mat.	70.00	70.00	70.00	70.00	70.00	70.00
Inventory charge	4.75	4.75	4.75	4.75	4.75	4.75

for construction. Three are boiling water reactors, the other three are pressurized water reactors. One BWR and one PWR has been chosen for each of three reactor sizes: small, medium, and large. For example, Dresden I, an operating reactor represents the small BWR's. Table A-II lists the six sample reactors and their size and type category.

TABLE A-II

REFERENCE REACTORS

	<u>Small</u>	<u>Medium</u>	<u>Large</u>
BWR	Dresden-1	Dresden-2	Proposed G. E. 1000 MW _e
PWR	Yankee	Connecticut Yankee	Indian Point-2

	<u>MW_e</u>
Yankee	134
Dresden-1	200
Connecticut Yankee	464
Dresden-2	715
Indian Point	873
Proposed G. E.	1000

A computer code, MYRA, developed by Royes Salmon of the Oak Ridge National Laboratory,⁽¹⁵⁾ was used for calculating the cost of shipping spent fuels from each type of reactor to a Hanford reprocessing plant. MYRA, published in August 1964, allows the study of variable cooling time on shipment costs. Cooling times of 90, 120, 150, and 180 days were used in this study. Table A-III a through A-III f lists the results of the computer code and defines the shipping cost in terms of \$/kg of reference material as it relates to the number of elements being shipped, the number of days cooled, and the total combined weight of cask and spent fuel.

TABLE A-III a
EFFECT OF NUMBER OF ELEMENTS PER CASK AND COOLING TIME
ON SPENT FUEL SHIPPING COSTS
Dresden-1

90 Days Cooling Time			120 Days Cooling Time			150 Days Cooling Time			180 Days Cooling Time		
Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight 1000 lb	Elements per Cask	\$/kg	Weight 1000 lb
1	36.65	46	1	36.04	45	1	35.73	44	1	35.57	43
2	23.97	61	2	23.70	59	2	23.60	57	2	23.61	56
4	15.14	72	4	15.08	70	4	15.14	68	4	15.26	67
8	10.52	96	8	10.59	93	8	10.72	92	8	10.89	90
16	7.33	123	16	7.48	119	16	7.67	117	16	7.89	116
32	5.55	164	32	5.73	161	32	5.94	158	32	6.17	156
43	5.23	190	45	5.47	193	45	5.67	190	45	5.90	188
45	5.29	198	46	5.42	194	50	5.64	201	50	5.87	198
48	5.20	201	51	5.38	204	55	5.43	208	55	5.66	206
50	5.30	211	52	5.35	204	56	5.40	208	56	5.63	206
51	5.28	212	56	5.20	212	57	5.65	224	57	5.90	223
53	5.19	220	57	5.45	228	58	5.64	226	59	5.84	224
54	5.17	221	58	5.43	229	64	5.55	232	64	5.78	230
55	5.15	222	59	5.41	230						
52	5.13	223	60	5.39	231						
57	5.40	241	64	5.39	239						
64	5.39	254									

TABLE A-III b

EFFECT OF NUMBER OF ELEMENTS PER CASK AND COOLING TIME
ON SPENT FUEL SHIPPING COSTS

Yankee

90 Days Cooling Time			120 Days Cooling Time			150 Days Cooling Time			180 Days Cooling Time		
Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb
1	17.65	58	1	17.47	56	1	17.43	54	1	17.47	53
2	13.08	86	2	12.40	77	2	12.47	75	2	12.60	74
3	12.59	128	4	8.38	95	4	8.51	92	4	8.69	91
4	14.84	206	8	7.29	144	8	7.12	132	8	7.23	128
5	18.20	315	9	7.10	154	11	7.09	166	13	6.72	165
8	34.51	864	11	7.79	196	13	6.79	177	15	6.53	171
			12	7.92	210	14	6.75	182	16	6.73	184
			13	8.10	230	15	6.74	189	17	6.65	187
			16	9.50	307	16	7.01	205	18	6.86	200
						17	7.07	213	19	6.98	210
						18	7.37	231	20	6.99	215
						32	12.76	548	21	7.00	220
									32	9.08	364

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TABLE A-III_c
EFFECT OF NUMBER OF ELEMENTS PER CASK AND COOLING TIME
ON SPENT FUEL SHIPPING COSTS
Dresden-2

90 Days Cooling Time			120 Days Cooling Time			150 Days Cooling Time			180 Days Cooling Time		
Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb
1	26.69	65	1	26.32	63	1	26.16	61	1	26.12	60
2	18.12	87	2	17.97	84	2	17.97	82	2	18.04	81
4	11.73	104	4	11.76	101	4	11.87	99	4	12.03	97
8	8.51	141	8	8.61	137	8	8.78	134	8	8.97	133
16	6.11	182	16	6.28	177	16	6.48	174	16	6.70	172
18	5.97	192	21	5.55	193	22	5.89	205	23	5.88	203
21	5.42	202	24	5.34	211	25	5.49	209	26	5.50	207
22	5.54	218	25	5.29	214	27	5.31	220	28	5.48	218
23	5.31	220	26	5.08	216	28	5.24	220	29	5.54	229
24	5.23	222	27	5.13	227	30	5.33	246	32	5.26	235
27	5.12	246	29	5.21	245	32	5.05	240			
29	5.12	260	31	4.99	252	33	5.01	241			
30	5.13	267	33	4.91	257	34	5.02	248			
32	4.89	273	35	5.19	293	35	5.31	279			
34	4.90	286	37	4.99	299	41	4.98	293			
35	5.25	322	64	5.22	485	42	4.95	295			
64	6.14	636				43	4.93	297			
						44	4.91	300			
						45	4.98	311			
						64	4.97	421			

TABLE A-III d
EFFECT OF NUMBER OF ELEMENTS PER CASK AND COOLING TIME
ON SPENT FUEL SHIPPING COSTS

Connecticut Yankee

90 Days Cooling Time			120 Days Cooling Time			150 Days Cooling Time			180 Days Cooling Time		
Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb
1	20.38	74	1	20.19	71	1	20.17	70	1	20.22	69
2	14.54	103	2	14.52	100	2	14.60	98	2	14.74	97
4	9.88	127	4	9.98	124	4	10.14	122	4	10.34	120
8	7.46	182	8	7.55	176	8	7.74	173	8	7.96	171
9	7.05	190	9	7.15	183	12	6.84	214	11	7.46	209
10	6.61	193	11	7.11	217	13	6.75	220	13	6.93	216
11	7.08	227	12	6.73	220	16	6.38	241	14	6.75	219
14	6.58	227	13	6.62	227	17	6.37	249	15	6.46	221
16	6.50	275	16	6.30	251	19	6.51	274	16	6.54	235
17	6.45	282	18	6.58	283	21	6.23	282			
18	6.62	302	19	6.49	288	22	6.52	307			
19	6.91	327	21	6.26	300	24	6.58	325			
20	6.77	337	22	6.59	327	25	6.61	334			
21	6.80	348	23	6.72	344	26	6.59	339			
22	7.23	382	24	6.71	351	27	6.79	359			
32	9.13	603	32	7.02	416	32	7.02	416			

TABLE A-IIIe
EFFECT OF NUMBER OF ELEMENTS PER CASK AND COOLING TIME
ON SPENT FUEL SHIPPING COSTS
General Electric 1000 MW_e

90 Days Cooling Time			120 Days Cooling Time			150 Days Cooling Time			180 Days Cooling Time		
Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb
1	36.96	60	1	36.39	58	1	36.12	57	1	35.99	56
2	24.78	80	2	24.54	77	2	24.48	76	2	24.50	74
4	15.74	95	4	15.70	92	4	15.77	90	4	15.89	89
8	11.17	127	8	11.24	124	8	11.38	122	8	11.55	120
16	7.88	163	16	8.04	159	16	8.23	156	16	8.45	155
24	6.55	191	27	6.62	198	27	6.83	196	25	6.56	212
27	6.45	203	31	6.38	214	31	6.59	211	30	6.91	208
31	6.23	220	32	6.15	214	32	6.37	211	32	6.60	209
32	6.02	221	33	6.12	217	34	6.26	214	34	6.49	212
39	5.82	264	34	6.05	217	35	6.47	240	35	6.71	238
42	5.71	271	35	6.25	243	45	5.80	260	64	5.45	314
44	5.48	274	43	5.61	257	50	5.61	272			
47	5.52	290	45	5.65	270	55	5.40	290			
48	5.33	291	48	5.39	273	56	5.38	292			
49	5.44	305	51	5.43	289	57	5.58	315			
50	5.43	309	53	5.46	300	64	5.35	331			
51	5.42	312	54	5.46	303						
52	5.40	314	56	5.27	307						
53	5.47	325	57	5.49	331						
64	5.41	392	64	5.29	352						

TABLE A-III f
EFFECT OF NUMBER OF ELEMENTS PER CASK AND COOLING TIME
ON SPENT FUEL SHIPPING COSTS
Indian Point-2

90 Days Cooling Time			120 Days Cooling Time			150 Days Cooling Time			180 Days Cooling Time		
Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb	Elements per Cask	\$/kg	Weight, 1000 lb
1	17.55	87	1	17.35	84	1	17.36	82	1	17.44	81
2	12.79	122	2	12.65	117	2	12.75	114	2	12.90	113
3	10.52	145	4	8.71	145	4	8.82	141	4	9.02	139
4	9.92	180	5	8.08	163	8	7.01	206	8	7.13	199
5	10.21	240	6	7.77	186	9	6.69	217	9	6.79	208
8	13.96	566	7	7.08	194	10	6.42	228	10	6.41	212
			8	7.15	226	12	6.57	278	11	6.78	249
						13	6.58	294	13	6.47	269
						14	6.40	306	15	6.15	283
						16	6.64	351	16	6.28	304

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APPENDIX B

The Outlook for Neptunium Requirements

At present the Nuclear Fuel Service Corporation does not have the special equipment necessary to separate neptunium, because much of NFS base load comes from NPR fuels which have a relatively low concentration of neptunium. Recently NFS has discussed expansion of their neptunium separations capability to the extent of a \$1,000,000 expenditure program. It has been estimated that in 2 years Nuclear Fuel Service will have a neptunium capability.

The General Electric reprocessing plant, on the other hand, has announced from the start that their separations plant will have the ability to separate neptunium. General Electric's reprocessing plant should be in operation by late 1970.

In March of 1966, in a meeting at Savannah River the British proposed that the sale of up to 20 kg of 99 percent pure neptunium oxide at \$75/gram could be supplied within 2 years. The AEC has shown interest in this proposal, but the latest reports have not indicated that the AEC has purchased any of the British neptunium. If such a purchase were to take place, it may be reasonable to assume that the AEC would also be interested in purchasing neptunium from U. S. suppliers at an equivalent price.

NFS was questioned sometime ago about their supply price of neptunium, and at that time they suggested a price somewhere between \$150 and \$250 per gram. This price may not be too far out of line if the economics of a base load containing a large percentage of NPR fuel is considered. The price would likely drop considerably if NFS's base load were shifted from NPR to commercial power reactors.

From the utility standpoint, the power industry seems to be justified in requesting about \$40/gram for the neptunium simply on the basis of neutron capture. This could amount to as much as \$6000/ton of discharge and would help considerably to pay for separation charges.

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