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A CONCEPTUAL DESIGN AND A COST ESTIMATE OF AN ON-SITE FACILITY
FOR CLEANING, DISASSEMBLING, AND CANNING SHORT-COOLED LMFBR
FUEL IN PREPARATION FOR SHIPMENT TO A CENTRAL REPROCESSING PLANT

B. C. Finney
R. S. Lowrie
C. D. Watson

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CHEMICAL TECHNOLOGY DIVISION

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A CONCEPTUAL DESIGN AND A COST ESTIMATE OF AN ON-SITE FACILITY
FOR CLEANING, DISASSEMBLING, AND CANNING SHORT-COOLED LMFR
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R. S. Lowrie
C. D. Watson

ABSTRACT

This report presents a conceptual design and a preliminary cost estimate for a fuel preshipment preparation facility that would be located at a 1000-Mw(electrical) sodium-cooled fast-breeder-reactor station. This facility would provide means for cleaning, disassembling, sorting (separating BeO rods from fuel rods), canning, and loading spent fuel rods (into casks) prior to shipment to a central reprocessing plant. The fuel would be allowed to cool for 10 to 25 days before the start of these operations. The facility would consist of a sodium removal area, a spent-fuel storage pool, a mechanical cell containing equipment for disassembling fuel elements, and a pool in which fuel cans could be stored and casks would be loaded.

The design of the facility and associated equipment was only sufficiently detailed to allow a scoping type of cost estimate to be made. Based on present-day costs, the capital cost of the facility is estimated to be \$5,050,000, and the annual operating cost (including amortization at 15%/year, operation, and waste disposal) is estimated to be \$1,062,000. Assuming a reactor load factor of 80%, the unit cost of disassembling, sorting, and canning amounts to 0.152 mill/kwhr; shipment of the fuel to a central reprocessing plant will cost an additional 0.029 mill/kwhr. Thus the total unit cost of preprocessing operations would be 0.181 mill/kwhr.

From this preliminary study, it is apparent that the cost of such a facility would be prohibitive for a single reactor; however, if the cost could be distributed among six or more reactors, the facility could be justified economically.

1. INTRODUCTION

In July 1966 a program aimed at developing and evaluating aqueous methods for processing short-cooled fast-breeder-reactor (FBR) fuel was initiated at the Oak Ridge National Laboratory. The ultimate goal of this program is the preparation of equipment and chemical flowsheets, and the accumulation of data necessary to complete a conceptual design and a cost estimate of a central reprocessing facility. The cost of shipping the spent fuel from the reactor site to the reprocessing facility will be included in the estimate.

Conceptual designs of 1000-Mw(electrical) FBR's indicate that burnups of 100,000 Mwd/metric ton (Pu + U) will be attained for the core. In order to minimize the out-of-reactor inventory cost, a short turn-around time for plutonium would provide a definite economic advantage. In any consideration of FBR fuel reprocessing, the mode of transporting the short-cooled fuel must be established because of the large quantity of decay heat that must be dissipated during shipment. In a recent preliminary cost study by Salmon,¹ two principal problems involved in reprocessing FBR fuel were studied: heat removal during shipment and the effect of inventory charges during the time that the fuel is being cooled before reprocessing. Salmon concludes that the disassembly of fuel prior to shipping should be seriously considered, in order to optimize heat dissipation and shipping charges. His cost estimate for shipping [\$11.20 per kg (U + Pu) after 20 days of cooling and \$10.40 per kg (U + Pu) after 90 days of cooling] did not include the cost of preshipment preparation. In earlier studies, Nicholson^{2,3} determined that FBR fuel would have to be cooled for at least 150 days before it could be processed in an existing plant (Nuclear Fuel Services, Inc.).

This report describes a conceptual design study, and presents a preliminary cost estimate, of a fuel preshipment preparation facility that would be located at a 1000-Mw(electrical) liquid-metal-cooled, oxide-fueled fast-breeder reactor (LMFBR) site. It was assumed that,

on discharge of each fuel assembly from the reactor, the neutron shield is removed and the fuel assembly is passed through a sodium cleaning station and is then stored in a water-filled canal. After a suitable period of cooling (10 to 20 days), the fuel assemblies are transferred from the storage canal to the mechanical cell, where the gas plenum chamber is removed. The multitubular bundle is then disassembled into individual rods, the BeO rods are separated from the fuel rods, the wire wrapping is stripped from the fuel rods, and the fuel rods are inserted into a can (21 rods to a can). This can is sealed and placed inside a 100-ton shipping cask, which is subsequently shipped to a central reprocessing plant.

The conceptual design of the facility and associated equipment was sufficiently detailed to allow only a scoping type of cost estimate to be made.

2. SUMMARY

The capital cost of the preshipment preparation facility, including structures, equipment, and auxiliaries, is estimated to be \$5,050,000. The annual operating cost, including an amortization rate of 15%/year, operation, waste disposal, and shipment, is estimated at \$1,264,000. Assuming a reactor load factor of 80%, the unit cost of cleaning, disassembly, sorting, canning, and shipment amounts to 0.181 mill/kwhr. Although this study is preliminary, it reveals that the cost of such a facility as designed for one reactor is prohibitive. However, the facility could be justified, on an economic basis, if the cost was distributed among six or more 1000-Mw(electrical) reactors.

3. REFERENCE FAST-BREEDER-REACTOR FUEL

An LMFBR (the General Electric Reference Sodium Cooled Fast Breeder Oxide Reactor) was chosen for this study because it appears to be nearer present-day capabilities than either the carbide- or

the metal-fueled fast breeder. The reference reactor is based on the design that was originally presented in GEAP-4418 (ref. 4) and was extensively modified in a subsequent study, GEAP-4939 (ref. 5). The core material consists of $\text{PuO}_2\text{-UO}_2$ pellets having an initial Pu enrichment of 17.9%. The upper and lower axial blankets are composed of depleted UO_2 pellets; there is no radial blanket. The core and the axial blankets are contained within the same fuel rod and thus are processed simultaneously. The complete fuel assembly has the shape of an enclosed hexagon, measuring 7.718 in. across the flats and 24 ft long, including a reusable 13-ft neutron shield. The reactor is refueled every six months to replace approximately one-fourth of the fuel. This results in an annual fuel discharge of approximately 18.9 tons. The interior volume of the reactor is designated as Zone 1, and the exterior volume as Zone 2. Each zone is made up of both complete and partial hexagons, which allow for insertion of control rods.

A summary of the pertinent physical characteristics of the fuel rods and the fuel assemblies for the reference reactor is presented in Table 1. A more complete description may be found in GEAP-4939 (ref. 5).

The condition of the spent fuel on discharge from the reactor is shown in Table 2, and the approximate amounts of decay heat released after various cooling times are summarized in Table 3. The amount of decay heat released in each instance was calculated by using Arnold's PHOEBE Code,⁶ which is based on ^{235}U fission. Decreasing the burnup of the core from 127,270 to 50,000 Mwd/metric ton (U + Pu) results in only a 10 to 25% (depending on the cooling time) decrease in the amount of decay heat released.

4. DESIGN CRITERIA

The following assumptions and ground rules were established as a basis for the conceptual design and the cost estimate of the

Table 1. Summary Data and Physical Characteristics
of the Reference Fuel Assemblies

Fuel Pin	
Overall length, in.	77.250
Outside diameter, in.	0.267
Cladding thickness, in.	0.010
Cladding material - AISI type 316 stainless steel	
Pin spacers--spiral wire wrap (0.032 in. diam)	
Length, lower axial blanket section, in.	18.0
Length, fuel section (core), in.	16.0
Length, upper axial blanket section, in.	18.0
Length, fission gas vent section, in.	24.0
Hexagonal Fuel Assembly	
Overall length, in.	131.0
Width across hexagon flats, in.	7.718
Thickness of fuel assembly sheath, in.	0.139
BeO pins in complete hexagon	
Zone 1	126
Zone 2	43
Fuel pins in complete hexagon	
Zone 1	420
Zone 2	503
BeO pins in partial hexagon	
Zone 1	114
Zone 2	38
Fuel pins in partial hexagon	
Zone 1	376
Zone 2	452
Total amount (U + Pu), as charged, per assembly	
Zone 1, complete hexagon, kg	141.54
Zone 1, partial hexagon, kg	126.74
Zone 2, complete hexagon, kg	169.51
Zone 2, partial hexagon, kg	152.33
Distribution of Fuel Assemblies in Reactor	
Complete hexagons	
Zone 1	34
Zone 2	107
Partial hexagons	
Zone 1	53
Zone 2	88
Fuel assemblies discharged during refueling	
Complete hexagons	
Zone 1	8
Zone 2	10
Partial hexagons	
Zone 1	27
Zone 2	18

Table 2. Summary Data for Spent Reference Fuel

Core	Zone 1	Zone 2
Exposure, Mwd/metric ton (U + Pu)	127,270	116,050
Fuel lifetime, days	708	942
Specific power, kw/kg	180	123
Axial Blankets (upper and lower)		
Exposure, Mwd/metric ton (U + Pu)	10,153	9,966
Fuel lifetime, days	708	942
Specific power, kw/kg	14.34	10.6

Table 3. Decay Heat Released by Reference Fuel

Cooling Time (days)	Decay Heat Release (Btu/hr)		
	Core	Axial Blankets ^a	Total
Zone 1: Complete Hexagon			
5	77,046	14,545	91,591
10	61,775	11,695	73,470
20	47,067	8,845	55,912
30	38,631	7,272	45,903
60	26,457	5,012	31,469
90	20,505	3,833	24,338
120	16,698	3,145	19,843
150	13,930	2,654	16,584
Zone 2: Complete Hexagon			
5	63,974	12,027	81,001
10	51,490	9,680	61,170
20	39,420	7,415	46,835
30	32,583	6,126	38,709
60	22,482	4,226	26,708
90	17,560	3,300	20,860
120	14,400	2,700	17,100
150	12,121	2,279	14,400

^aUpper and lower.

facility for cleaning, disassembling, canning spent-fuel assemblies prior to shipment to a central reprocessing plant.

1. The preshipment preparation facility will be located at the site of the 1000-Mw(electrical) sodium-cooled fast-breeder reactor, and will share utility services (electrical, water, steam, off-gas, etc.) with the reactor.
2. The reactor will be refueled every six months; 63 fuel assemblies will be discharged at each refueling. The first assembly will become available for reprocessing 10 days after reactor shutdown (based on refueling time cycles in GEAP-4418).⁴
3. The transfer device for removing spent-fuel assemblies from the reactor will also be used to load assemblies into the fuel cleaning vessel.
4. Sufficient argon cooling will be provided to remove:
 - (1) decay heat (1,225 Btu/min) from a 10-day-cooled, complete-hexagon fuel assembly located in Zone 1,
 - (2) the heat released (495 Btu/min) from the deactivation of 64 g of sodium per minute with water, and
 - (3) the heat introduced into the system via circulation of the argon.
5. The fuel rods will not be vented and will not normally contain sodium.
6. A water-filled storage basin or canal (capacity, 70 fuel assemblies) will be provided between the sodium removal facility and the mechanical disassembly facility. The canal cooling system will be equipped to remove the decay heat from the spent-fuel assemblies (average cooling time of 25 days, 2.7×10^6 Btu/hr).
7. The fuel assemblies will be disassembled into individual fuel rods containing a core and upper and lower axial

blanket sections. The fuel rods will be placed in sealed cans, which, in turn, will be placed in a grid in the shipping cask. The dual-purpose grid in the shipping cask restrains each can during shipment and provides the necessary heat transfer to the cask walls.

8. All the fuel will reach the central reprocessing plant within 30 days after reactor shutdown. The processing schedule required in order to meet this timetable is shown in Table 4. Processing will be limited to two 8-hr shifts per day; the third shift will be used for equipment maintenance, cleanup, and waste disposal.

Table 4. Time Schedule for Preshipment Preparation of Spent Reference Fuel Assemblies

Time After Reactor Shutdown (days)	No. of Assemblies			
	Cleaned	Stored	Disassembled and Canned	Shipped
10	--	--	--	--
11	5	1.0	4.0	--
12	10	1.0	9.0	--
13	15	2.0	13.0	9
14	20	2.0	18.0	--
15	25	3.0	22.0	18
16	30	3.0	27.0	--
17	35	4.0	31.0	27
18	40	4.0	36.0	--
19	45	5.0	40.0	36
20	50	5.0	45.0	--
21	55	6.0	49.0	45
22	60	6.0	54.0	--
23	63	5.0	58.0	54
24	--	--	63.0	--
25	--	--	--	63

5. FACILITY FOR REMOVING SODIUM AND DISASSEMBLING FUEL RODS

The conceptual facility consists of: an area in which sodium is removed from fuel assemblies; a pool for storing cleaned fuel assemblies; a mechanical cell that contains equipment for disassembling each fuel assembly into individual rods; equipment for separating the fuel rods and the BeO rods and then canning the fuel rods in sealed cans; a pool in which the latter cans are stored and casks are loaded; a cask washdown area; and a railroad spur for shipping loaded casks and receiving empty casks. A plan view of this facility is shown in Fig. 1. Detailed procedures for handling each fuel assembly are presented in Appendix A, and a detailed cost estimate for the facility is shown in Appendix B. A general description of the various items of equipment to be used in the facility is presented in Sects. 5.1 and 5.2; a summary of the cost data may be found in Sect. 5.3.

5.1 Pool for Removing Sodium and Storing Fuel Assemblies

At some point in the flowsheet for processing LMFBR fuel by an aqueous method, the sodium adhering to the surfaces of spent-fuel assemblies discharged from the reactor must be deactivated and removed. Currently, residual sodium on EBR-II and Fermi reactor fuel assemblies is removed by deactivating it with steam, and then washing with water to remove the product (NaOH) of reaction. Modifications of this procedure have been proposed for LMFBR fuels.^{7,8} To meet the reprocessing schedule shown in Table 4, a facility for removing sodium by using water must also be capable of removing both the decay heat from 10-day-cooled fuel assemblies ($\sim 73,000$ Btu/hr for a full hexagon located in Zone 1, see Table 3) and the heat released by the sodium-water reaction as shown below:⁹

$$\Delta H_{298^\circ\text{F}} = -45.7 \text{ kcal/mole.}$$

Fig. 1 On-Site Facility for Preparing Spent Fuel from a 1000-Mw (electrical) Fast-Breeder Reactor for Shipment to a Central Reprocessing Plant.

A recycling argon gas stream will, by necessity, be used to remove the heat; the sodium-water heat release will be governed by the controlled injection of steam into the carrier gas.

The sodium removal station will consist of a cleaning vessel (Fig. 2) located in the top section of a 4.5 x 4.5 x 35 ft deep water-filled storage basin (Fig. 3). To prevent water from entering the reactor environment, spent-fuel assemblies will be moved from the reactor in a transfer cask (probably equipped with its own gas cooling system), which will mate with the entry port of the cleaning vessel. After the assembly has been lowered into the cleaning vessel, it will be positioned with the sealing shoes and the floating head will be clamped onto the top of the assembly. Argon will flow down through the assembly, then upward through the annulus between the vessel and the assembly, exiting to pass through the blower and heat exchangers before being recycled. Steam (50 g/min) will be metered into the gas stream to deactivate the sodium, and the assembly will be dropped into a shock-absorber-equipped transfer mechanism and will be moved through the transfer tunnel to a rack in the fuel surge basin, where it will be cooled for a suitable period of time. (The 10 x 16 x 30 ft deep basin will accommodate 70 assemblies.) The water in the interconnecting storage basin, transfer tunnel, and cleaning pit will be circulated, first through a demineralizer (e.g., to remove small amounts of NaOH, etc.) and then through a heat exchanger that is large enough to remove the decay heat from the 63 cleaned fuel assemblies (cooled for 20 days).

5.2 Disassembly, Canning, and Shipping

The mechanical cell is contained in a shielded facility that is approximately 36 ft long x 12 ft wide x 20 ft high and is equipped with necessary auxiliary equipment such as windows, coolers, manipulators, crane, etc. Cleaned spent-fuel assemblies are transferred from the storage basin to the underwater disassembly section of the mechanical cell through an access port and gate. Disassembly is

PARTS LIST										STOCK SIZE		MATERIAL	
PART	QTY	NO.	REQD	DESCRIPTION		DATE		APPROVED		DATE		APPROVED	
1	1	1	1	CLEANING VESSEL LOWER SECTION		11/24/44		EM		003		REV	
2	1	1	1	SHIELD PLUG VALVE PLUG, 4" DIA		11/24/44		EM		003		REV	
3	1	1	1	GENERAL ASSEMBLY		11/24/44		EM		003		REV	
4	1	1	1	FUEL ASSEMBLY		11/24/44		EM		003		REV	
5	1	1	1	FLOATING HEAD PIVOT CYLINDER		11/24/44		EM		003		REV	
6	1	1	1	SWIVEL JOINT		11/24/44		EM		003		REV	
7	1	1	1	GAS & WATER INLET PORT		11/24/44		EM		003		REV	
8	1	1	1	CLAMP SCREW DRIVE AIR MOTOR		11/24/44		EM		003		REV	
9	1	1	1	3 SECTION CLAMP		11/24/44		EM		003		REV	
10	1	1	1	CLAMP SUPPORT PLATE		11/24/44		EM		003		REV	
11	1	1	1	BOTTOM HEAD PIVOT CYLINDER		11/24/44		EM		003		REV	
12	1	1	1	DRAIN PORT		11/24/44		EM		003		REV	
13	1	1	1	3 SECTION CLAMP		11/24/44		EM		003		REV	
14	1	1	1	SEAL RING		11/24/44		EM		003		REV	
15	1	1	1	BOTTOM HEAD		11/24/44		EM		003		REV	

Fig. 2 Vessel for Removing Sodium from Spent Fuel Rods.

Fig. 3 Equipment Layout for Sodium Removal Station and Pool for Storing Cleaned Fuel.

performed stepwise under water in order to facilitate the removal of decay heat. First, the massive lower end adapter and the gas plenum section of the fuel assembly are severed by abrasive disk sawing and are then removed. Second, the rods (fuel and BeO) are separated from the sheath, placed in a hopper, lifted out of the water, and placed in the cell. In the cell, individual rods are fed to a wire stripper for removal of the wire wrapping. Then, the heavier fuel rods are separated from the BeO rods by a technique utilizing their difference in weight. Fuel rods are inserted into dried cans (21 rods/can), which are transferred to a capping station. After the cans have been sealed, they are transferred under water by a conveyor from the mechanical cell either to the storage rack or directly to the shipping cask.

In order to meet the requirements of the timetable presented in Table 4, the disassembly and canning equipment in the mechanical cell may have to be of the operator-aided, automatic, or the semi-automatic type. It should be noted that, with the exception of the canning facilities, a mechanical cell (for fuel disassembly) similar to the one described would be required regardless of whether the fuel is disassembled at the reactor site prior to shipping or after receipt at a central reprocessing plant and prior to reprocessing.

5.3 Summary of Cost Data

The conceptual design of the on-site facility, including structures, auxiliary equipment, and processing equipment, was detailed only to the extent required for obtaining a scoping type of cost estimate. The time for disassembling and repackaging for shipment is sufficiently short that operator-aided, automatic, or semiautomatic equipment would be required. It may be necessary to install duplicate processing lines for various phases of the operation. Actually, automated high-speed equipment handling large quantities of highly irradiated, short-decayed fuel has never been operated in a shielded cell; consequently, both the design of the

facility and the cost estimate are simply based on the extension of present-day technology. A summary of cost data follows:

A. Capital Costs

1. Sodium removal station	\$ 419,000
2. Fuel assembly storage pool	434,000
3. Mechanical cell	1,999,000
4. Disassembly equipment for mechanical cell	745,000
5. Fuel storage cans and casks	924,000
6. Decontamination cell	367,000
7. Service facility (staff shop)	<u>162,000</u>
Total	\$5,050,000

B. Annual Cost

1. Amortization (6-2/3 years at 15%/yr)	\$ 758,000
2. Operating	300,000
3. Waste Disposal	<u>4,000</u>
Subtotal	\$1,062,000
1. Shipping (based on \$11.20/kg (Pu + U), as determined by Salmon)	<u>202,000</u>
Total	\$1,264,000

C. Unit Cost

Assuming an 80% load factor for the 1000-Mw(electrical) General Electric Reference Oxide Fast Breeder Reactor, the annual electrical output is 7×10^6 kwhr. The unit cost, based on this assumption, is:

1. Preshipment preparation (cleaning, disassembling, sorting, canning, and loading into casks)	0.152 mill/kwhr
2. Shipment	<u>0.029 mill/kwhr</u>
Total unit cost	0.181 mill/kwhr

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APPENDIX A: SUGGESTED PROCEDURES FOR
HANDLING SPENT FUEL FROM THE GENERAL ELECTRIC REFERENCE FBR

Suggested stepwise procedures for handling spent fuel from the General Electric Reference Oxide Fast Breeder Reactor fuel as it is processed through the on-site preshipping preparation facility are described below.

Sodium Removal and Storage of Fuel Assemblies

1. The transfer cask containing one fuel assembly is moved from the reactor to the fuel cleaning station and mated to the entry port of the cleaning vessel.
2. The space between the valve on the bottom of the transfer cask and the valve on the entry port of the cleaning vessel is purged with argon.
3. Both valves are opened, and the fuel assembly is lowered to the bottom of the cleaning vessel. The lowering device is retracted into the transfer cask, both valves are closed, and, after the space between the valves has been cleaned and purged, the cask is disconnected and returned to the reactor for use with the next fuel assembly.
4. After the fuel assembly has been clamped in place with the sealing shoes and the floating head has been positioned over the top of the assembly, the flow of argon cooling gas is started.
5. The loaded cleaning vessel is cooled to the desired operating temperature before steam (50 g/min) is injected into the gas stream to deactivate the sodium.
6. Hydrogen concentration in the recycle gas stream is controlled by venting a small side stream to the off-gas system.
7. The deactivated sodium (NaOH) is washed from the fuel assembly by filling the vessel with water, which is recirculated through the assembly for a given period and is then pumped to a waste system.

8. During a second water wash, the transfer mechanism is moved into place, and the water level between the storage pool and the water depression chamber around the cleaning vessel (see Fig. 3) is equalized.

9. After the second water wash (but while the cleaning vessel is still full of water), the bottom closure is opened and the sealing shoes are released so that the fuel assembly is allowed to fall into the transfer mechanism. The free-fall energy is absorbed by a shock absorber.

10. The transfer mechanism is moved through the transfer tunnel to the storage pool, and the assembly is moved (by a grapple on the bridge crane) to a predetermined position in the storage racks.

11. The cleaning vessel and the water depression chamber are pressurized with argon to effect removal of the water before the bottom closure on the cleaning vessel is secured.

12. Moisture in the cleaning vessel (and associated piping) is removed via circulation of hot ($\sim 220^{\circ}\text{F}$) argon. The vessel is then ready to receive the next fuel assembly.

Disassembling, Sorting, and Canning of the Spent Fuel, and Loading of the Cask

1. After a suitable cooling period, the fuel assembly is transferred from the storage pool to the storage rack in the surge basin by means of a grapple and a bridge crane.

2. A transfer mechanism swings the fuel assembly through the access port and gate in an approximate horizontal position onto the lock elevator by gravity.

3. The fuel assembly is then transferred, by means of a lock-to-saw transfer mechanism from the lock elevator, through a port and gate, to the cut-off saw feed table.

4. The adapter end of the fuel is pushed against a stop plate to properly index the fuel in preparation for sawing off each end.

5. The fuel is secured with a pair of clamps that are mounted on a cross-feed mechanism.

6. The fuel is fed into a pair of abrasive saw wheels on a cross-feed mechanism. Spacer wires (which are welded to the end plugs) along with the end adapter and the gas plenum chamber, are severed. Special handling of individual fuel rods may be required to remove the spacer wires if they are welded in locations other than at the end plugs.

7. The sawed fuel is aligned with a hydraulic cylinder indexing device, and the fuel tubes are pushed out of the sheath into a trough. Two types of pusher heads will be required for the two types of assemblies (complete and partial hexagons).

8. The individual fuel rods are picked up on a pair of notched wheels, and transferred to a trough. A hydraulic cylinder, with a stroke of approximately 2 in., pushes each rod through a hole that is sized to permit passage of the rod and to exclude the spacer wire. When the end of the rod passes through the hole, it is forced into a pair of rotating rollers that pull the remainder of the rod through the hole. Two rotating fingers clear the spacer wire from the trough.

9. The spacer wires are compacted into a bundle, sheared into short lengths, or coiled into rolls in such a manner that they occupy minimal space in the waste disposal containers.

10. The plenum chambers, end adapters, and spacer wires are stored in a waste container for subsequent burial. Some of the sheaths can be loaded vertically into a scrap container, and the void areas can be filled with BeO rods and other scrap. The unused sheaths are flattened for burial. Waste containers are loaded into a shielded carrier that is located in a shielded lock.

11. The fuel rods and the BeO rods pass through a balancing mechanism that separates them according to weight. The fuel rods are discharged onto a conveyor that feeds into an indexing mechanism.

This mechanism loads 21 rods into a compartmented, 2-in. pipe container.

12. The loaded pipe containers are transferred to a capping station where a positive seal cap is attached. The seal cap can either be welded shut or mechanically attached. The containers are then lowered onto a second conveyor.

13. The latter conveyor transfers each container to a position where it can be transferred to a tilting mechanism.

14. The tilting mechanism raises each container to a vertical position and lowers it into the storage basins, onto a horizontal conveyor that carries it to the area where shipping casks are loaded. Here the container is transferred to another conveyor, which positions it adjacent to the shipping cask to minimize the time required for final transfer to the cask.

15. The storage basin bridge crane, which is provided with a special handling tool, picks up each container by a tool post (that is located on the container cap) and loads it into the shipping cask. A movable guide plate is inserted into the end of the shipping cask to make the transfer of each container into the shipping cask grid easier.

16. After the shipping cask has been loaded, the end plug is attached. The cask is then ready to be removed from the water. It should be thoroughly drained before shipping.

17. A container storage area is provided to allow fuel to be disassembled even though a shipping cask is not ready or available for loading.

18. Reverse procedures are used for unloading empty containers from the shipping cask and transferring them into the the disassembly cell. If the containers do not contain seal caps, the water is dumped from the containers via the tilting mechanism. Then each container is placed on a conveyor that elevates it into a suitable position for drying prior to reloading.

APPENDIX B: DETAILED COST ESTIMATE

The detailed cost estimate for the on-site facility for removing the sodium and disassembling the fuel elements follows:

Capital Costs

1. Sodium removal facility

A. Building allocation

1. Reactor building space and services (not included)	--
2. Alpha enclosure	\$ 12,000
3. Alpha filters and vent ducting	<u>8,000</u>
Subtotal	\$ 20,000

B. Major equipment

1. Alpha-tight shield valve	\$ 4,000
2. Shield plug and valve manifold	15,000
3. Water depression chamber	10,000
4. Cleaning vessel--upper section	7,000
5. Cleaning vessel--lower section	7,000
6. Off-gas system	10,000
7. Gas cooler	5,000
8. Cooling water chiller	14,000
9. Compressor and motor drive	60,000
10. Mufflers and aftercooler	2,000
11. Waste tank and pump	3,000
12. Water pressure booster system	2,000
13. Process valves	<u>20,000</u>
Subtotal	\$159,000

C. Equipment Installation	\$ 35,000
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D. Piping	50,000
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E. Electrical	10,000
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F. Instrumentation	<u>30,000</u>
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Subtotal	\$304,000
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G. Engineering (15%)	<u>45,000</u>
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Subtotal	\$349,000
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H. Contingencies (20%)	\$ <u>70,000</u>
Total	\$419,000
2. Fuel assembly storage pool	
A. Building allocations	
1. Space and services for reactor building	--
2. Space and services for disassembly facility	--
3. Storage pool, tunnel, and cleaning pit	\$ <u>85,000</u>
Subtotal	\$ 85,000
B. Major equipment (including installation)	
1. Heat exchangers and pumps	\$ 40,000
2. Cooling tower and auxiliaries	55,000
3. Demineralizer system	30,000
4. Filter system	5,000
5. Crane for handling fuel assemblies (2-ton)	25,000
6. Service bridge	10,000
7. Fuel assembly grapple	2,000
8. Storage racks	8,000
9. Mechanism for transferring fuel assemblies from the cleaning station to the storage pool	<u>20,000</u>
Subtotal	\$195,000
C. Piping	\$ 25,000
D. Electrical	5,000
E. Instrumentation	<u>5,000</u>
Subtotal	\$315,000
F. Engineering (15%)	<u>47,000</u>
Subtotal	\$362,000
G. Contingencies (20%)	<u>72,000</u>
Total	\$434,000
3. Disassembly facility	
A. Building allocation	
1. Shielded cell structure	\$573,000
2. Building Services	<u>44,000</u>
Subtotal	\$617,000

B. Major equipment (cell)

1. Coolers	\$ 32,000
2. Viewing windows	226,000
3. Decontamination cell door	58,000
4. Waste removal lock and hatch cover	39,000
5. Master-slave manipulators	22,000
6. Bridge power manipulator	100,000
7. Extended-reach, heavy-duty master-slave manipulator	56,000
8. Bridge crane	99,000
9. Television system	69,000
10. Drain filters	<u>10,000</u>
Subtotal	\$711,000

C. Electrical equipment

1. Process equipment	\$ 50,000
2. Special lighting	<u>11,000</u>
Subtotal	\$ 61,000

D. Service piping

	<u>60,000</u>
Subtotal	\$1,449,000*

E. Engineering (15%)

	<u>217,000</u>
Subtotal	\$1,666,000

F. Contingencies (20%)

	<u>333,000</u>
Total	\$1,999,000

4. Disassembly, Canning, and Storage of Spent Fuel

A. Mechanical equipment

1. Waste chutes, tray, etc.	\$ 2,000
2. Pool to lock transfer mechanism	9,000
3. Lock elevator	13,000
4. Lock to saw transfer mechanism	6,000
5. Dual-blade cut-off saw	38,000
6. Feed table for cut-off saw	8,000
7. Ejector station	10,000

* Cost estimate is based on published Nuclear Fuel Services, Inc.'s cost.

8. Tube hopper and elevator	\$ 8,000
9. Tube singulator	8,000
10. Wire stripper	5,000
11. Separator and loader	7,000
12. Can drying station	3,000
13. Fuel-can loading station and transfer mechanism	8,000
14. Horizontal conveyor in cell	8,000
15. Vertical conveyor in cell	8,000
16. Clamp and tilting mechanism	2,000
17. Decapping mechanism	8,000
18. Seal-cap transfer station	3,000
19. O-Ring stripping mechanism	2,000
20. O-Ring feeding mechanism	1,000
21. Canal horizontal conveyor	37,000
22. Fuel-can storage rack	7,000
23. Fuel-can handling tool	9,000
24. Waste removal carriers (5 at \$29,100 each)	145,000
25. Fuel rod cans	<u>35,000</u> **
Subtotal	\$390,000
B. Structural supports for equipment	\$ 25,000
C. Cell-water cooling system	25,000
D. Electrical controls and interlocks	50,000
E. Equipment installation	<u>50,000</u>
Subtotal	\$540,000
F. Engineering (15%)	<u>81,000</u>
Subtotal	\$621,000
G. Contingencies (20%)	<u>124,000</u>
Total	\$745,000

** Cost estimate is based on number of fuel cans (2304) required to fill 12 shipping casks, plus the number (192) in the loading canal. The total cost has been divided between ten reactors.

5. Fuel-can storage and cask loading

A. Building allocations

1. Structure	\$300,000
2. Pool	75,000
3. Services	<u>20,000</u>

Subtotal \$395,000

B. Major Equipment

1. Coolers	\$ 5,000
2. Pumps	3,000
3. Gates	2,000
4. Filters	1,000
5. Demineralized-water tank	6,000
6. Car pullers	6,000
7. Cask unloading crane	111,000
8. Crane for use in fuel pool	26,000
9. Service bridge	10,000
10. Grappler	2,000
11. Demineralizer	20,000
12. Exhausters	3,000
13. Railroad doors	7,000
14. Heaters	2,000
15. Cask inspection scaffolding	<u>1,000</u>

Subtotal \$205,000

C. Service piping

50,000

D. Electrical equipment

20,000

Subtotal \$670,000*

E. Engineering (15%)

100,000

Subtotal \$770,000

F. Contingencies (20%)

154,000

Total \$924,000

6. Decontamination cell

A. Structure and auxiliaries

Subtotal \$266,000*

B. Engineering (15%)	\$ 40,000
Subtotal	\$306,000
C. Contingencies (20%)	<u>61,000</u>
Total	\$367,000
7. Service facility	
A. Staff shop	\$117,000*
B. Engineering (15%)	<u>18,000</u>
Subtotal	\$135,000
C. Contingencies (20%)	<u>27,000</u>
Total	\$162,000
Grand Total	<u>\$5,050,000</u>

Annual Costs

1. Amortization (6-2/3 years at 15%/year)	\$ 758,000
2. Operating	300,000
3. Waste disposal	<u>4,000</u>
Subtotal	\$1,062,000
1. Shipping (based on an annual discharge of ~ 18,000 kg (Pu + U) and shipping charge of \$11.2/kg (Pu + U) as determined by Salmon)	
	<u>\$ 202,000</u>
Total	\$1,264,000

Unit Cost Determination

Assuming that the 1000-Mw(electrical) General Electric Reference Oxide Fast Breeder Reactor operates with a 80% load factor, the annual electrical output would be 7×10^9 kwhr. Based on this factor, the unit cost is as follows:

1. Preshipping preparation (sodium removal; disassembling, sorting, and canning the fuel rods; and loading the rods into the cask)	0.152 mill/kwhr
2. Shipping	<u>0.029 mill/kwhr</u>
Total	0.181 mill/kwhr

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