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ECONOMICS OF WATER BASIN STORAGE OF SPENT LIGHT WATER REACTOR FUEL

by

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INTRODUCTION

The deferral of spent fuel reprocessing will necessitate the storage of all spent reactor fuel. Even with the maximum use of increased fuel storage in current spent fuel storage basins at each reactor site, capacity of reactor site storage is expected to be exceeded in the 1980's. For the long term, storage in geologic formations may be the most desirable mode, particularly if reprocessing is not resumed. However, because of the long lead time in preparing for geologic storage, some additional surface storage may be required. In the International Spent Fuel Storage (ISFS) Program, interim storage in central water-filled basins is being studied.

The Department of Energy (DOE) is considering offering to assume responsibility for disposing of spent fuel for utilities for a one-time fee. This one-time fee for some or all of the

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transferred spent fuel would include a charge for capital and operating costs of interim storage.

Preliminary estimates of basin costs and possible alternative fees are presented in this report.

SUMMARY

As part of the ISFS program, a preliminary Venture Guidance Assessment of the cost was made by the Du Pont Engineering Department. The escalated cost of a reference facility with a capacity to receive 2000 MT/yr of spent LWR fuel and to store 5000 MT in water-filled pools was converted to $180 million in 1978 dollars for a stand-alone facility. It was estimated that the receiving rate could be increased to 3000 MT/yr for an additional $15 million and that increments could be added to the storage capacity for $13 million per 1000 MT. If a receipt rate of more than 3000 MT/yr is required, a new facility in another part of the country might be built to reduce total costs including transportation.

Operating costs are determined by the number of people employed and by the costs of stainless steel baskets. An operating crew of 150 is required for the reference facility; the associated cost, including overhead and supplies, is $6 million. During an extended storage-only period, this cost is assumed to drop to $4 million. Fuel baskets are estimated to cost $6.20/kg of spent fuel averaged over a reactor mix of two-thirds Pressurized Water Reactors (PWR) and one-third Boiling Water Reactors (BWR). The nominal basket

requirements of $10 million for the first year are capitalized. If the facility is financed by the government and a one-time fee is charged to recover all of the away-from-reactor (AFR) basin costs, the fee is about $60/kg of spent fuel plus any government surcharge to cover research and development, overhead, and additional contingencies. If the facility is financed by industry with an annual charge that includes a fixed charge on capital of 25%, the annual fee is about $16/kg-yr. In calculating both fees, it is assumed that each storage position is occupied for ten years. The Du Pont Engineering Department is expected to provide a more detailed, budget-quality estimate in the fall of 1978 for a basin with the capacity of this reference facility. However, it is anticipated that the revised estimate will be based on a larger and more elaborate design than the one on which this paper is based and that the cost will be appreciably greater.

DETAILS

The Engineering Department made a preliminary Venture Guidance Assessment of $210 million as the cost of the reference water-basin storage facility for spent LWR fuel. This facility is considered as a satellite to an established plant. A drawing of the facility is given in Figure 1. A breakdown of the cost is given in column 1 of Table 1. This total is de-escalated by a factor of 1.24 to give $169 million in 1978 dollars. Additional costs for a stand-alone plant are $8 million for a steam plant, $2 million for waste facilities, and $3 million for land purchase compared to site modifications in the satellite facility. The total of $182 million is rounded to $180 million, and the breakdown is given in column 2 of Table 1. The cost of the main building of $73 million is allocated to three areas according to relative volumes and unit costs as summarized in Table 2.

The incremental costs of increasing the receiving rate to 3000 MT/yr are summarized in the third column of Table 1. The receiving area is divided into four handling areas. As indicated in Figure 1, the required number of each handling area to achieve 2000 MT/yr is given in the first column of figures:

Handling Area	*Number Required*	
	2000 MT/Yr	*3000 MT/Yr*
Preparation and Cask Offload-Load	3	4
Cask Cool and Wash	2	2
Fuel Unloading Pool	2	2
Cask Decontamination	2	3

The number of handling areas required for 3000 MT/yr is also indicated. It is assumed that the volume of each handling area is proportional to the number of stations. Changing from a receiving rate of 2000 to 3000 MT/yr increases the volume of the receiving areas by 24% and the building cost by 20%. It is assumed that there is a small increase in the volume of the personnel area. The cost of cranes is assumed to increase by 30%. The costs of heating and ventilation scale as the .8 power of the building volume. Steam generation requirements are nearly proportional to heating and ventilation needs. Design and inspection costs amount to 20% of the cost of the reference facility; it is assumed that they amount to 10% of the cost of the receiving-rate increment.

When the storage capacity is doubled, as in the last column of Table 1, it is assumed that the area containing ten water basins is duplicated. Thus, both storage area building costs and process area costs are doubled. The cost of water treatment is assumed to scale as the .8 power of the number of pools and water cooling costs are doubled. Again heating and ventilation and steam generation scale as the 0.8 power of building volumes. Design and inspection costs are assumed to be 5% of the incremental cost.

Assuming costs are stepwise linear, the capital cost of a storage facility, including the first year's supply of baskets, is approximately

$$C = 85 + 15R + 13S$$

R is the receiving rate in thousands of metric tons (kMT) per year, and S is the storage capacity in kMT, both rounded to the next higher integer. If all basket costs and decommissioning costs are included,

$$C = 85 + 17R + 20S$$

Operating costs are determined by the number of people employed and by the cost of fuel baskets. An operating crew of 150 is required in the reference facility while fuel is being received or shipped. Details are given in Table 3. At a cost of $40,000 per person, including overhead and operating supplies, the labor-related cost is $6 million/yr when fuel is being received or shipped. The annual operating cost is assumed to be $4 million during an extended storage-only period. For a facility with a receiving rate of 3000 MT/yr and a storage capacity of 10,000 MT, the operating cost is assumed to be $8 million while receiving or shipping fuel and is $5 million during a storage-only period.

As summarized in Table 4, fuel baskets are estimated to cost $6.20/kg of fuel averaged over a reactor mix of two-thirds PWR and one-third BWR. The cost of the first year's requirement for baskets, $10 million, is capitalized. Subsequent basket costs are treated as operating costs.

The method used to calculate possible fees for the reference facility is illustrated in Table 5. An annual schedule of capital, operating, and total costs is given. An assumed schedule for fuel receipts is also shown. It is assumed that each fuel assembly is stored for 10 years. The resulting average inventory is given in the last column. Costs are discounted to year-5, the assumed year of initial fuel receipt. This procedure is equivalent to adding interest during construction before startup. The total cost is related to the annual cost by

$$C = \sum_{i=1}^{18} C_i/(1 + d)^{(i - 5)}$$

where d is the discount rate. As mentioned earlier, escalation is not accounted for and all costs are in 1978 dollars. An annual charge for fuel stored can be defined by setting the present worth of the total storage costs, C, equal to the present worth of the fees received, F. Annual charges are taken to be operating costs plus a fixed charge on capital times the present worth of capital expenditures in year 5. If the fixed charge on capital is assumed to be 0.25, the annual charges given in column 6 of Table 5 are obtained. If the annual unit-storage fee in 1978 dollars, f, is assumed to be independent of time, the present worth of fees received is

$$F = \sum_{i=5}^{17} f\,\bar{I}_i/(1 + d)^{(i - 5)}$$

where $\bar{I}_i$ is the average inventory in year, i.

Thus,

$$f = \left[\sum_{i=1}^{18} C_i/(1+d)^{(i - 5)}\right] / \left[\sum_{i=5}^{17} \bar{I}_i/(1 + d)^{(i - 5)}\right]$$

as shown numerically at the bottom of Table 5. The actual fee in year i will be higher than f by the escalation experienced in those (i - 5) years.

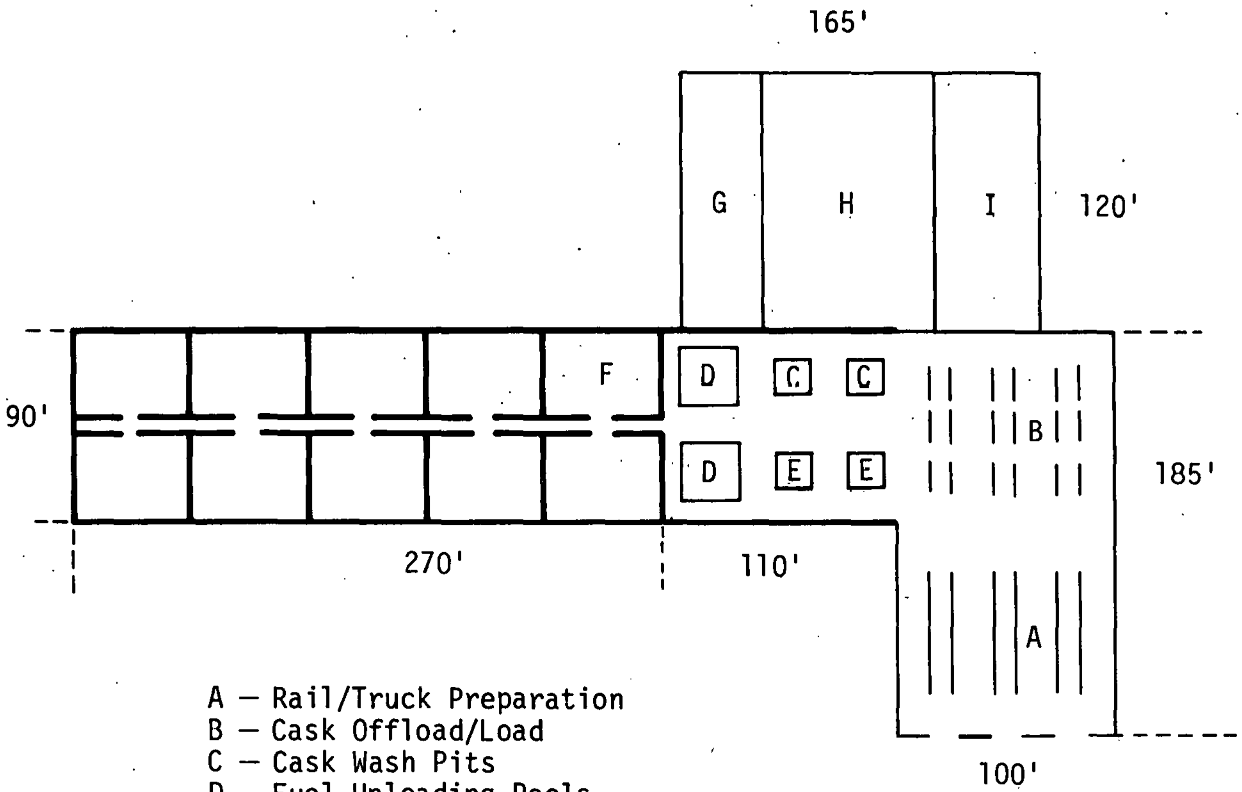
Under some circumstances, a one-time fee at the time of fuel receipt might be preferred. To recover full facility costs, the present worth of fees received is again set equal to the present worth of total facility costs as indicated at the bottom of Table 5. Similar calculations are given in Table 6 for a larger facility.

These fees are summarized in Table 7. One-time fees are indicated in Part A both for a discount rate of 10%, which is used by the government for comparing alternatives, and 6½%, which is used by the government in calculating fees such as separative work fees. If the facility is government financed, a surcharge might be added to cover government overhead, research and development, and additional contingencies. Annual charges are given in Part B. To facilitate comparison with the one-time fees, the present worth of a series of five and ten annual charges is also indicated.

One other costing alternative can be considered. Consider a single project in which 60,000 MT of spent fuel is assumed to be shipped from reactor basins. The fuel will be shipped directly to geologic storage if possible. Prior to the availability of geologic storage, assume that 10,000 MT must be stored temporarily in AFR basins. The AFR basin costs can be considered as one component of a one-time uniform fee applied to the total fuel transferred. This situation is summarized in Table 8. The AFR basin costs and fuel receipts are from Table 6. The total fuel received by the project is approximated in the last column. The unit cost of $70/kg when basin costs are spread over 10,000 MT was derived previously. The unit cost if the AFR basin costs are spread over 60,000 MT is $22.66/kg.

The total undiscounted cost of the AFR basin is $430 million in 1978 dollars plus an assumed $215 million in surcharges. If only fuel stored in the AFR basin is charged for the AFR basin cost, component fees of $700 million are received in years 5-8.

If all fuel is charged uniformly for the AFR basin costs, AFR component fees of $1360 million are received in years 5 - 22. The year-5 present worth of all three of these dollar distributions is $600 million.



A — Rail/Truck Preparation
B — Cask Offload/Load
C — Cask Wash Pits
D — Fuel Unloading Pools
E — Cask Decontamination Pits
F — Fuel Storage Basins
G — Heating and Ventilation
H — Process Equipment
I — Personnel Facilities

FIGURE 1. Layout of Main Building Reference Case

TABLE 1

Capital Costs of AFR Water Basin Storage Facilities

	Eng. Dept.[a]	*Reference Facility*[b]	*Increments to Receiving*	*Increments to Storage*
Escalation Year	1981	1978	1978	1978
Receiving Rate, MT/yr	2,000	2,000	3,000	2,000
Storage Capacity, MT	5,000	5,000	5,000	10,000
Costs, $ Millions				
Fuel Building - Receiving Area	-	31	6	-
Storage Area	115	36	-	36
Process/Personnel	-	6	1	3
Cranes - Receiving/Storing	10	6	2	1
Electrical - Substations & Diesels	3.5	2	-	1
Lighting & TV - Area & Underwater	4	3	-	2
Water - Treatment	16	10	-	8
Cooling	6.5	4	-	4
Steam Generation	3	10	1	2
Heating & Ventilation	12.2	7	1	2
Waste Handling	4.5	5	-	-
Instrumentation	5.9	4	1	2
Services (Health Physics, Computer, Fire, etc.)	10.0	6	-	-
Site Work	2.6	2	1	1
Design and Inspection	-	33	2	3
Fuel Storage Baskets (First Year)	15	10	-	-
Land Purchase/Modifications	2	5	-	-
Total	210	180	15	65
Decommissioning	-	20	2	6

a. Design, inspection, allowance, contingency, and escalation costs are distributed.

b. Allowance and contingency costs are distributed.

TABLE 2

Main Building Volumes and Relative Costs

Area	*Volumes, Millions ft³* *Hardened*	*Standard*	*Relative Cost*[a]
Receiving	0.85	1.24	0.491
Storage	1.25	0.61	0.424
Process/Personnel	0	0.78	0.085

a. Based on $\$7.75/ft^3$ for hardened construction and $\$2.50/ft^3$ for standard construction.

TABLE 3

Operating Manpower for Reference Basin

	Manpower
Administration	3
Operations	85
Maintenance and Services	14
Technical	11
Clerical	12
Safeguards	25
Total	150

TABLE 4

Basket Costs

Reactors	.667 PWR	.333 BWR
Annual Discharge, MT	16.97	9.77
No. of Assemblies	36.8	53.3
No. of Racks[a]	9.2	5.9
Cost, $ thousands	82.7	82.9

Unit Cost of Racks = $\$165.6 \times 10^3/26.74$ MT = \$6.19/kg

a. A PWR rack is assumed to hold four fuel assemblies and to cost \$9000. A BWR rack holds nine fuel assemblies and costs \$14,000.

TABLE 5

Calculation of Storage Basin Fees

Receiving Rate - 2000 MT/yr; Capacity - 5000 MT
Discount Rate = .10

Year	*Cost, $ Million*				*Annual Charge*[a]	*Receive/ Ship, kMT*	*Average Inventory, kMT*
	Capital	*Operating Baskets*	*Operating Oper.*	*Total*			
1	10			10			
2	15			15			
3	71			71			
4	84		3	87			
5		5	6	11	65.7	1.6	0.8
6		10	6	16	70.7	1.7	2.5
7		6	6	12	66.7	1.7	4.2
8			4	4	58.7		5.0
9			4	4	58.7		5.0
10			4	4	58.7		5.0
11			4	4	58.7		5.0
12			4	4	58.7		5.0
13			4	4	58.7		5.0
14			4	4	58.7		5.0
15			6	6	60.7	-1.6	4.2
16			6	6	60.7	-1.7	2.5
17			6	6	60.7	-1.7	0.8
18	20			20			
Total	200	21	67	288	796.1	5.0	50.0
Discounted Total	218.7	19	42.1	279.9	485.3	4.55	29.41

a. .25 (discounted capital in year 5) + Operating = $54.7 million + Operating Cost

Annual Fee - 485.3/29.41 = $16.51/yr

One-Time Charge = 279.9/4.55 = $61.50

TABLE 6

Calculation of Storage Basin Fees

Receiving Rate = 3000 MT/yr; Capacity = 10,000 MT
Discount Rate = .10

	Cost, $ Million						
		Operating					*Average*
Year	*Capital*	*Baskets*	*Oper.*	*Total*	*Annual Charge*[a]	*Receive/ Ship, kMT*	*Inventory, kMT*
1	10			10			
2	17			17			
3	76			76			
4	95		3	98			
5	29	9	6	44	91	2.0	1.0
6	33	15	6	54	97	2.0	3.0
7		19	8	27	103	3.0	5.5
8		9	8	17	93	3.0	8.5
9			5	5	81		10.0
10			5	5	81		10.0
11			5	5	81		10.0
12			5	5	81		10.0
13			5	5	81		10.0
14			5	5	81		10.0
15			6	6	82	-2.0	9.0
16			7	7	83	-2.0	7.0
17			8	8	84	-3.0	4.5
18			8	8	84	-3.0	1.5
19	28			28			
Total	288	52	90	430	1203	10.0	100.0
Discounted Total	300.1	45.1	53.4	398.6	711	8.55	55.17

a. .25 (discounted capital in year 5) + Operating = $76 Million + Operating

Annual Fee = 711.0/55.17 = $12.89/yr

One-Time Charge = 398.6/8.55 = $46.60

TABLE 7

Typical Unit Costs for Water Basin Storage

Basin - Receiving rate, MT/yr	2,000		3,000	
- Capacity, MT	5,000		10,000	
Alternative Cost Methods				
A. Single charge, $/kg, when fuel is received				
Discount rate	.065	.10	.065	.10
Storage charge, $/kg	59	61	45	47
Possible surcharge, $/kg	30	31	23	24
Total charge, $/kg	89	92	68	71
B. Annual charge on fuel inventory[a]				
Discount rate		.10		.10
Annual charge, $/kg-yr		16.50		12.90
PW of 5 years' storage, $/kg		69		54
PW of 10 years' storage, $/kg		112		87

a. Assuming that each storage position is occupied for 10 years.

TABLE 8

Calculation of Storage Basin Fees as a Component of a Uniform Fee for All Five-Year-Old Spent Fuel

Year	*Total Cost, $ Millions*	*Annual Fuel Receipts, kMT*	
		AFR Basin	*Total*[a]
1	10		
2	17		
3	76		
4	98		
5	44	2	2
6	54	2	2
7	27	3	3
8	17	3	3
9	5		2
10	5		2
11	5		3
12	5		3
13	5		3
14	5		3
15	6		3
16	7		4
17	8		4
18	8		4
19	28		4
20			5
21			5
22			5
Total	430	10	60
Discounted[b] Total	399	8.55	26.38
Unit Cost		46.60	15.11
+ 50% Surcharge	598	69.90	22.66
Total, $ Million	430 (Spent)	699 (Received)	1360 (Received)

a. Including fuel going directly to geologic storage.

b. Discounted to year 5 at d = 0.10.