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 Time Prior to Shipping to Disposal Site

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1.0 INTRODUCTION

One of the potentially attractive schemes for the ultimate disposal of radioactive waste is simply to pour the waste into pits. The best geological location for these pits may not coincide with the optimum location for a processing plant and transport will be required.

It may be necessary or desirable to remove some fission products from the waste, particularly the long-lived activities, prior to disposal into the ground. The influence of fission product removal on shipping costs will depend on which elements are removed and to what extent. Since no firm flowsheet has been generally accepted for this step, its effect on waste disposal economics is not considered in this memo.

As waste is cooled, the cost of storage increases and the cost of shipping decreases by virtue of having to ship less shield weight. The optimum cooling time will depend on the irradiation history of the fuel, the cost of storage and the cost of shipping.

2.0 SUMMARY

For 250 gallon batches of waste (800 gal/ton) from fuel irradiated 400 days to 10,000 MWD/T, optimum cooling times were determined. Three distances between processing and disposal sites, and three unit storage costs were considered. The results appear in the following table:

Table I Optimum Cooling Times			
Storage Cost \$/gal/yr	0.013	0.041	0.30
Type Storage	Hanford	Hanford	Idaho, S.R.
Ownership	Government	Private	Private
Optimum Cooling Time (years) for One-Way Shipping Distance of:			
200 mi.	9	6-1/2	0
500 mi.	11	7-1/2	5-1/2
1000 mi.	14	9	6-1/2

The conclusions that can be drawn are that as the storage cost increases it becomes economical to ship shorter cooled waste. As the shipping distance increases, it becomes economical to store waste longer. In the case of 30¢/gal/yr storage, for 200 miles shipment, essentially no storage should be provided beyond that required for surge in filling carriers.

The above conclusions are based on 10,000 MWD/T fuel. For less highly irradiated material, the optima would shift in the direction of shorter cooling times.

3.0 STORAGE COSTS

Tank storage of liquid wastes may be an essential step in a scheme for ultimate waste disposal. Storage reduces the heat generation and radiation problems attendant with shipping and subsequent processing. As an example, the rate of heat generation for fuel irradiated a long time (to fission product saturation) at 25 MW/ton is shown in Figure 1 as a function of cooling time; 800 gallons of waste per ton have been assumed.

To determine an optimum storage time to be employed in the overall storage - shipment - treatment - disposal cycle, an estimate of the cost of storing a unit volume per unit time is necessary. The following assumptions were made:

- (1) Lifetime of underground storage tank of 50 years
- (2) Purex-type waste
- (3) Tank farm operating personnel of 2 men/shift.

Cost data available were:

Hanford 15,000,000 gallon tank farm (including diversion boxes, piping to existing lines overhead): \$0.16/gal.

Savannah River 4,800,000 gallon tank farm (including cooling coils, condenser, filter): \$1.44/gal.

Idaho 300,000 gallon tank farm (stainless steel vessels): \$1.77/gal.

Fixed charges were calculated for initial investments of \$0.25 and \$2.00 per gallon at three different annual rates. 12 percent and 15 percent per year represent the range used by utility companies to write off investments inclusive profit, taxes, and interest on capital. 4 percent per year might be the rate for a government-owned burial site (2 percent amortization plus 2 percent average interest).

The cost of land $\frac{\$5000/\text{acre}}{1,000,000 \text{ gal/acre}} = \$0.005/\text{gal}$ was neglected compared to the initial cost of tankage.

Direct operating costs (based on a 20,000,000 gallon form which has reached steady state) will be:

$$\frac{2 \text{ men/shift} \times 4 \text{ shifts} \times \$4500/\text{man-year}}{20,000,000 \text{ gal}} = \$0.0018/\text{gal/year}$$

Allowing for 67 percent overhead, the direct charge will be \$0.003/gal/year.

The calculated unit charges for the six cases are tabulated below:

Table 2 Unit Storage Costs (\$/gal/yr)			
\$0.25/gal Initial Investment			
Rate for Fixed Charge	15%	12%	4%
Fixed Charge	0.038	0.030	0.010
Direct Charge	0.003	0.003	0.003
Total	0.041	0.033	0.013

Table 2 (cont'd)			
\$2.00/gal Initial Investment			
Rate for Fixed Charge	15%	12%	4%
Fixed Charge	0.30	0.24	0.08
<u>Direct Charge</u>	<u>0.003</u>	<u>0.003</u>	<u>0.003</u>
Total	0.30	0.24	0.08

4.0 SHIELDING REQUIRED FOR SHIPPING WASTE

The number of curies of a fission product per watt of reactor operating power will be:

$$\frac{\text{Curie}}{\text{Watt}} = \frac{3.1 \times 10^{10} \text{ fission/sec/watt}}{3.7 \times 10^{10} \text{ dis/sec/curie}} (Y_1)(1-e^{-\lambda_1 t_0})(e^{-\lambda_1 t_c}) = 0.84 Y_1(1-e^{-\lambda_1 t_0})e^{-\lambda_1 t_c}$$

Where: Y_1 = fraction fission yield

λ_1 = decay constant, day⁻¹

t_0 = reactor operating time, days

t_c = cooling time, days

A typical (based on Project Separations tabulation) reactor specific power of 1000 MW/40 T = 25 MW/T is assumed. On this basis, the reactor operating time for various irradiation levels is tabulated below:

Table 3	
Operating Time for Various Irradiation Levels	
<u>MW D/T</u>	<u>Days Operating</u>
2000	80
4000	160
8000	320
10000	400

Fission products to be considered for the shielding calculations are Ba¹⁴⁰(La¹⁴⁰), Zr⁹⁵, Nb⁹⁵, Ce¹⁴⁴(Pr¹⁴⁴), Cs¹³⁷ and Ru¹⁰⁶(Rh¹⁰⁶). The following table gives the solutions for the number of curies of each of these fission products present at time of discharge from the reactor for various reactor operating times.

Table 4						
Curies Per Watt at Discharge Time						
Nuclide	λ_1	Y_1	Curies/watt Reactor Power for Operating Time of:			
			80 day	160 day	320 day	400 day
Ba ¹⁴⁰ (La ¹⁴⁰)	0.0541	0.063	0.052	0.053	0.053	0.053
Nb ⁹⁵	0.0198	0.064	0.042	0.051	0.054	0.054
Zr ⁹⁵	0.0107	0.064	0.031	0.044	0.052	0.053
Ce ¹⁴⁴ (Pr ¹⁴⁴)	0.00239	0.061	0.0087	0.016	0.027	0.031
Cs ¹³⁷	5.75×10^{-5}	0.059	2.5×10^{-4}	4.5×10^{-4}	8.9×10^{-4}	1.1×10^{-3}
Ru ¹⁰⁶ (Rh ¹⁰⁶)	0.0019	0.0038	4.5×10^{-4}	8.3×10^{-4}	1.5×10^{-3}	1.7×10^{-3}

Figures 2-5 show the curies/watt for each of the above fission products as a function of irradiation and cooling times.

Since 800 gallons of high activity waste per metric ton and a specific power of 25×10^6 watts have been assumed: $\text{curies/gal} = \frac{A(\text{curies/watt}) \times 2.5 \times 10^7}{800} = 3.1 \times 10^4 A$

The curies/gal are tabulated below for 400 days irradiation at 25 MW/ton:

Table 5
Curies/gal for Various Cooling Times

Nuclide	γ Energy(Mev)	%	γ curies/gal for cooling time of:					
			100 day	500 day	1000 day	3000 day	10000 day	30000 day
La ¹⁴⁰	3.0	1	0.068	--	--	--	--	--
	2.5	5.4	0.37	--	--	--	--	--
	1.5	94	6.4	--	--	--	--	--
Nb ⁹⁵	0.75	100	240	0.084	--	--	--	--
Zr ⁹⁵	0.73	100	560	7.4	0.035	--	--	--
Pr ¹⁴⁴	2.2	1	7.7	3.1	1.0	1.4×10^{-4}	--	--
	1.5	2	15.4	6.2	2.0	2.8×10^{-4}	--	--
	0.7	4	30.8	12	4.0	5.6×10^{-4}	--	--
Cs ¹³⁷	0.66	92	31	31	29	23	18	6.2
Rh ¹⁰⁶	2.4	0.25	0.11	0.053	0.020	--	--	--
	1.6	0.5	0.22	0.11	0.041	--	--	--
	1.0	2	0.86	0.41	0.16	--	--	--
	0.9	1	0.43	0.21	0.08	--	--	--
	0.6	12	5.2	2.5	0.97	--	--	--

Shielding calculations were made for a 4 foot I.D. carrier holding 250 gallons of waste from fuel irradiated 400 days (10000 MWD/T). A maximum permissible dose rate of 10 mr/hr at the wall of a 9 foot wide railroad car was the basis for determining the shield thickness. The method of KLX-24 gave the results found in Table 6.

Table 6
Dosage at Wall of Car (400 days irradiation)

Energy Group	Days Cooling					
	100	500	1000	5000	10000	30000
2.2 Mev						
Curies-in ² /gal	5800	1800	580	---	---	---
mr/hr:						
no shielding	3.2×10^5	1.0×10^5	3.2×10^4	---	---	---
4" Pb	---	---	64	---	---	---
6" Pb	64	20	6.4	---	---	---
7" Pb	16	5.0	1.6	---	---	---
8" Pb	6.4	2.0	0.64	---	---	---

Energy Group	Days Cooling					
	100	500	1000	5000	10000	30000
<u>1.5 Mev</u>						
Curies-in ² /gal	1.3×10^4	3600	1200	---	---	---
mr/hr:						
no shielding	5.4×10^5	1.5×10^5	5.0×10^4	---	---	---
4" Pb	---	---	25	---	---	---
6" Pb	5.4	1.5	0.5	---	---	---
7" Pb	2.7	0.75	0.25	---	---	---
8" Pb	0.7	0.2	0.06	---	---	---
<u>1.0 Mev (Negligible compared to 1.5 Mev Group)</u>						
Curies-in ² /gal	750	30	120	---	---	---
<u>0.74 Mev</u>						
Curies-in ² /gal	4.6×10^5	4.3×10^3	---	---	---	---
mr/hr:						
no shielding	1.2×10^7	1.1×10^5	---	---	---	---
6" Pb	0.03	---	---	---	---	---
<u>0.66 Mev</u>						
Curies-Cu ² /gal	2.1×10^4	1.9×10^4	1.7×10^4	1.3×10^4	1.0×10^4	3600
mr/hr						
no shielding	---	4.3×10^5	3.8×10^5	2.8×10^5	2.2×10^5	8.1×10^4
2" Pb	---	---	38	28	22	8.1
3" Pb	---	---	---	0.93	0.73	0.27
4" Pb	---	---	---	---	0.02	0.008
<u>Total All Energies</u>						
mr/hr:						
2" Pb	---	---	---	28	22	8.1
3" Pb	---	---	---	0.94	0.73	0.27
4" Pb	---	---	89	---	0.022	0.008
6" Pb	69	22	6.4	---	---	---
7" Pb	19	5.8	1.0	---	---	---
8" Pb	7.1	2.2	0.7	---	---	---

Figure 6 is a plot of the total dose rate at the car wall as a function of the cooling time.

5.0 OPTIMIZATION OF COOLING TIME FOR SHIPPING WASTE

For a fixed irradiation, the combined cost of storage and shipping will be a function of cooling time and shipping distance.

Carrier weights are plotted as a function of shield thickness in Figure 7 for a 250 gallon waste capacity. Using the shield thicknesses from Figure 6 which gave a 10 mr/hr tolerance dose (for 400 day, 10,000 MWD/T irradiation) carrier weights were plotted as a function of cooling time in Figure 8.

It was assumed that the empty carrier must be returned to its point of origin and that carrier cost and handling charges would not be significantly influenced by cooling time compared to freight charges.

The freight charges (round trip) were computed on the following basis:

Table 7 Rail Freight Rates	
One Way Distance Miles	\$/CWT Round Trip
200	1.40
500	2.60
1000	4.50

The optimization was carried out for the three distances of the above table and for unit storage costs of \$0.013, \$0.041 and \$0.30 per gallon per year from Table 1. The basic costs appear in Tables 8 and the combined results in Table 9 and Figures 9-11.

Table 8 Storage and Shipping Costs as Functions of Cooling Time						
Cooling Time (Years)	Storage Cost (\$/gal)			Shipping Cost (\$/gal)		
	\$0.013/gal/yr	\$0.041/gal/yr	\$0.30/gal/yr	200 mi	500 mi	1000 mi
0.5	0.006	0.02	0.15	1.70	3.16	5.46
5	0.06	0.20	1.50	0.74	1.37	2.38
6	0.08	0.25	1.80	0.55	1.02	1.77
7	0.09	0.29	2.10	0.49	0.91	1.58
10	0.13	0.41	3.00	0.44	0.82	1.42
15	0.19	0.61	4.50	0.42	0.78	1.35
20	0.26	0.82	6.00	0.41	0.76	1.32
30	0.39	1.23	9.00	0.40	0.74	1.29

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Table 9

Combined Storage and Shipping Costs as a Function of Cooling Time (\$/gal)

Cooling Time (Years)	Storage at \$0.013/gal/yr			Storage at \$0.041/gal/yr			Storage at \$0.30/gal/yr		
	200 mi	500 mi	1000 mi	200 mi	500 mi	1000 mi	200 mi	500 mi	1000 mi
0.5	1.71	3.17	5.47	1.72	3.18	5.48	1.85	3.31	5.61
5	0.80	1.43	2.44	0.94	1.57	2.58	2.24	2.87	3.88
6	0.63	1.10	1.85	0.80	1.27	2.02	2.35	2.82	3.57
7	0.58	1.00	1.67	0.78	1.20	1.87	2.49	3.01	3.68
10	0.57	0.95	1.55	0.85	1.23	1.83	3.44	3.82	4.42
15	0.61	0.96	1.54	1.03	1.39	1.96	4.92	5.28	5.85
20	0.67	1.02	1.58	1.23	1.58	2.14	6.41	6.76	7.32
30	0.79	1.13	1.68	1.63	1.97	2.52	9.40	9.74	10.29

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FIG.1 WASTE HEAT GENERATION RATE AS A
FUNCTION OF COOLING TIME

BASIS: ∞ IRRADIATION TIME AT 25 MW / TON,
800 GALS WASTE / TON

WATTS / GAL OF WASTE

830-10

FIG. 2 Ba¹⁴⁰ - Nb⁹⁵ ACTIVITIES

ACTIVITY (CURIES / WATT OF VECTOR POWER)

FIG. 3 Zr^{95} ACTIVITIES

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ACTIVITY (CURIES / WATT)

COOLING TIME (DAYS) 830-12

FIG. 4 Ce^{144} - Ru^{106}
ACTIVITIES

ORNL-LR-DWG. 9549
UNCLASSIFIED

ACTIVITY (CURIES/WATT)

831-13

ORNL-LR-DWG. 9550
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16

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FIG. 10 COMBINED SHIPPING AND STORAGE COST AS A FUNCTION OF COOLING TIME.

BASIS:

1. STORAGE COST = \$ 0.041/gal.-yr.
2. SHIPMENT OF 250 gals. OF LIQUID IN SPHERE OF 4ft. I.D.
3. VOLUME OF WASTE PER TON OF SPENT FUEL = 800 gals.
4. IRRADIATION 400 DAYS TO 10,000 MWD/T.

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FIG. II COMBINED SHIPPING AND STORAGE COSTS
AS A FUNCTION OF COOLING TIME

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