ECONOMIC CONSIDERATIONS IN THE PACKAGING OF LOW-LEVEL RADIOACTIVE WASTE FOR LAND DISPOSAL

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ABSTRACT

Over the past few years there have been significant increases in the cost of disposal of low-level radioactive waste. Previously, disposal costs were primarily related to the volume of the waste. At present, surface radiation, specific activity and curie content have a major effect on costs and burial costs are no longer directly related to volume. A case study has been made to evaluate the cost of disposal in terms of "$ per curie" rather than "$ per cubic foot". With higher concentrations of specific activity, the unit costs of transportation, containers and burial are significantly reduced. Processes which increase the concentration of radioactive waste can be more beneficial than processes which only reduce volume. For concentrated waste, solidification can reduce the surface radiation of the containers. This allows casks to handle waste with higher initial specific activity and greater quantities of activity per shipment. Burial charges are also reduced because of lower radiation surcharges on a "$ per curie" basis. Aging the waste reduces the radiation levels and can reduce disposal costs.

INTRODUCTION

Over the past few years, significant changes have been made in the price schedules for burial of low-level waste. The prices for burial of low-level waste were traditionally based primarily on volume. Surcharges for radiation had been generally a secondary charge. In the most recent price schedules, the surcharges for both surface radiation and curie content have been increased to where these charges are greater than the burial charges based on volume alone.

The costs of packaging and transportation of low-level waste have also risen over the last few years. Custom fabricated steel liners and high integrity containers have replaced a significant portion of the 55-gallon steel drums previously used.

METHODOLOGY

In order to thoroughly evaluate the economics of low-level waste packaging, transportation and disposal, a review was made of existing and licensed radioactive material packages. It was determined which packages might be used to handle radioactive waste shipments with waste containers having radiation levels over range of 0.05 R per hour to 5000 R per hour. Twelve shipping configuration and radiation levels were selected as the "Cases" to be used in the economic evaluation. Table I lists the cases, the reference shipping package and the associated radiation levels.

TABLE I

RADIOACTIVE MATERIALS SHIPPING PACKAGES

Case	Certificate of Compliance	Cask Designation	Surface Radiation (R/hr.)
A	N/A	Unshielded	0.05
B	N/A	Shielded Van	0.2
C	9096	CNS-21-300	1.5
D	9151	HN-100	5.0
E	9151	HN-100	10
F	6601	CNS-8-120	50
G	6601	CNS-8-120	100
H	9159	NuPac 6-100 (with impact skirts)	200
I	9159	NuPac 6-100 (with impact skirts)	500
J	6574	HN-200	1000
K	6574	HN-200 (Shortened to 3 drums)	2000
L	9152	CNS 1-13 (lengthened to 2 drums)	5000

Table II lists the specific activity of the waste, the number and size of the waste containers and the total curies per shipment for each case. For each case, the following waste packages were considered:

- Solidified in steel liners
- Solidified in steel drums
- Dewatered in High Integrity Containers (HIC)
- Dewatered in HIC Drums

TABLE II

TRANSPORTATION AND BURIAL CONFIGURATIONS USED IN CASE STUDIES

Case	Surface Radiation (R per hr.)	Specific* Activity (μCi/ml)	Container Sizes No. @ CF	Total Activity (Curies)
		UNSHIELDED (Solidified)		
A	0.05	0.18	3 @ 170	2.1
			60 @ 7.5	2.1
		(Dewatered)		
A	0.05	0.04	3 @ 170	0.4
			120 @ 7.5	0.8
		(SHIELDED VAN) (Solidified)		
B	0.2	0.73	2 @ 170	6.2
			60 @ 7.5	8.4
		(Dewatered)		
B	0.2	0.16	2 @ 170	1.2
			80 @ 7.5	2.2
		L.S.A. > TYPE A (Solidified)		
C	1.5	5.5	1 @ 300	42
			21 @ 7.5	22
D	5	18	1 @ 170	78
			14 @ 7.5	49
E	10	37	1 @ 170	156
			14 @ 7.5	98
F	50	184	1 @ 120	520
			8 @ 7.5	281
G	100	367	1 @ 120	1040
			8 @ 7.5	561

TABLE II cont.

Case	Surface Radiation (R per hr.)	Specific* Activity (μCi/ml)	Container Sizes No. @ CF	Total Activity (Curies)
		(Dewatered)		
C	1.5	1.2	3 @ 300	8
			21 @ 7.5	4
D	5	4.0	1 @ 170	15
			14 @ 7.5	12
E	10	8.0	1 @ 170	30
			14 @ 7.5	24
F	50	40	1 @ 120	102
			8 @ 7.5	54
G	100	80	1 @ 120	204
			8 @ 7.5	109
		TYPE B (Solidified)		
H	200	734	1 @ 100	1872
			6 @ 7.5	832
I	500	1836	1 @ 100	4680
			6 @ 7.5	2080
J	1000	3672	1 @ 80	7487
			4 @ 7.5	2808
K	2000	7345	1 @ 50	9360
			3 @ 7.5	4160
L	5000	18362	1 @ 20	9360
			2 @ 7.5	6760
		(Dewatered)		
H	200	160	1 @ 100	340
			6 @ 7.5	163
I	500	400	1 @ 100	850
			6 @ 7.5	408
J	1000	800	1 @ 80	1360
			4 @ 7.5	544
K	2000	1600	1 @ 50	1540
			3 @ 7.5	816
L	5000	4000	1 @ 20	1700
			2 @ 7.5	1360

Transportation Costs

Transportation costs were evaluated based on one-way distances of 250, 500, 1,000, 1,500, 2,000 and 2,500 miles. The Interstate Commerce Commission mileage commodity rates for radioactive waste containers were used to compute transportation costs as follows:

Unshielded Shipments	-	One-way distance and mileage rates
Shielded Vans and L.S.A. > Type A Casks	-	Continuous excursion rates at twice one-way distance
Type B Casks	-	Twice one-way distance at one-way mileage rates

In addition, an allowance of 60 percent of the mileage costs was added to cover cask usage, permits and management of transportation operations.

Waste Composition

For purposes of estimating the specific activity and total activity of the waste as a function of the surface radiation, it was assumed that the waste was composed of equal quantities of the following radionuclides:

Cobalt-58
Cobalt-60
Cesium-134
Cesium-137

The specific activities shown on Table II were estimated from the surface radiation levels as shown in Table III using the method derived in Reference 1. The specific activity of the waste was calculated by dividing the surface radiation level by the appropriate combined surface radiation coefficient.

TABLE III

WASTE COMPOSITION AND RADIATION LEVELS USED IN ANALYSIS

Isotope	Specific Activity (μCi/ml)	Radiation Coefficient (R/hr. per μCi/ml)	Surface Radiation (R/hr.)
	Solidified Waste		
Cobalt-58	0.25	0.130	0.0325
Cobalt-60	0.25	0.519	0.1298
Cesium-134	0.25	0.384	0.0960
Cesium-137	0.25	0.056	0.0140
Combined	1.00	0.2723	0.2723
	Dewatered Resin		
Cobalt-58	0.25	0.750	0.1874
Cobalt-60	0.25	1.870	0.4675
Cesium-134	0.25	1.961	0.4903
Cesium-137	0.25	0.434	0.1085
Combined	1.00	1.2538	1.2538

Container Sizes and Costs

Table IV contains a listing of the types, sizes and costs of containers used in the analysis.

TABLE IV

TYPES, SIZES AND COST OF CONTAINERS USED IN ANALYSIS

Type	Burial Volume (CF)	Waste Volume (CF)	Unit Cost ($)
Steel Drums	7.5	6.7	$ 25
Steel Liners and (High Integrity Containers)	300	270 (225)	$6,000
	170	150 (130)	$4,000
	120	108 (90)	$3,000
	100	90 (75)	$2,500
	80	72 (60)	$2,000
	50	45 (34)	$1,200
	20	18 (15)	$ 500
HIC Drums	7.5	(6.0)	$ 250

Burial Costs

The burial costs used in this analysis are based on the rate schedules for the Barnwell Low-Level Radioactive Waste Disposal Facility effective January 1, 1984. The rate schedules for the western disposal sites were also examined. The rate schedules both on a "$ per cubic foot" and a "$ per curie" basis are similar for all three sites with the western sites having slightly lower surcharges and burial fees.

Cubic Feet versus Curies

Traditionally, economic studies of low-level radioactive waste disposal have been based on the volume of waste with costs expressed in $ per cubic foot. Since burial represents one of the major cost factors in the disposal of low-level radioactive waste, an initial evaluation was made to compare "cost per cubic foot" and "cost per curie" of waste to be buried.

Figure 1 shows the overall burial costs expressed in "$ per cubic foot" for the burial of solidified steel liners having surface radiation levels as indicated on Figure 1 and in Table II. This figure would indicate that the cost of burial increases significantly with increasing radiation level.

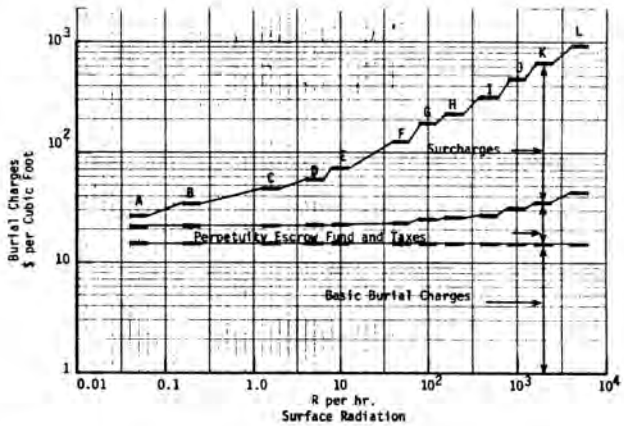

Fig. 1. Overall Burial Costs Based on Volume

Figure 2 shows the burial cost expressed in "$ per curie" calculated using the surface radiation levels and total activity per shipment listed in Table II.

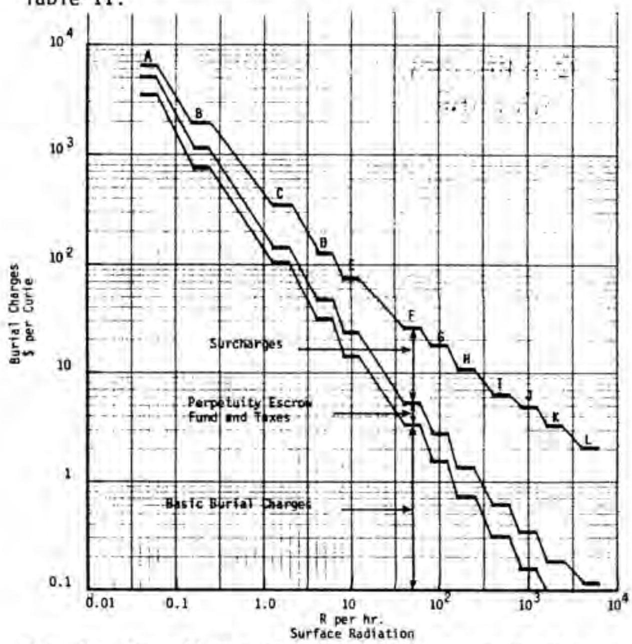

Fig. 2. Overall Burial Costs Based on Curie Content

As indicated in Figure 2, the cost of burial of radioactive material decreases significantly as the concentration of activity is increased. For unshielded shipments, the cost of burial is several thousands of dollars per curie. For Type B shipments with containers having surface radiation levels in excess of 200 R per hour, the cost of burial is less than $10 per curie.

For these reasons, the economic analysis was conducted using "$ per curie". This basis was used for packaging and transportation costs as well as burial.

Other

This analysis does not consider the costs associated with dewatering and solidification of the waste and other conditioning costs in preparation for shipment.

ANALYTICAL RESULTS

Burial

Figure 3 shows the unit cost of burial for each of the twelve cases using the four types of containers.

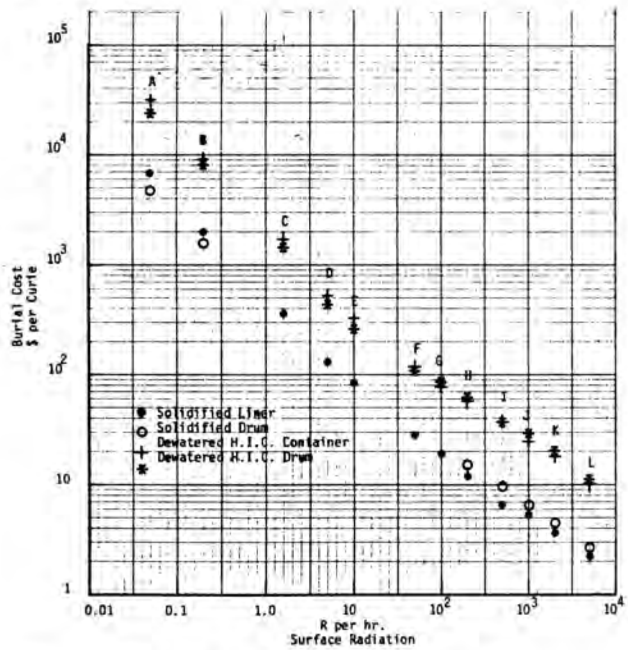

Fig. 3. Burial Costs for Various Containers

The results are summarized as follows:

- o For radioactive waste containers having the same surface radiation levels, the burial cost is lower for solidified material than dewatered material. The self shielding provided by the solidification material allows much greater amounts of activity to be shipped in a cask with the same amount of shielding.
- o The burial cost of solidified drums and steel liners is essentially the same. For unshielded shipments and shipments in shielded vans, drums have a slight cost advantage in terms of burial cost.
- o The burial costs of high integrity containers, both drums and large containers, are essentially the same for the same radiation level.
- o The burial cost of dewatered material in high integrity containers, both drums and larger containers, will be higher because of the low amounts of activity for a given surface radiation level.
- o The cost of solidification as compared to dewatering must be considered in selecting the type of container to be used.

Transportation and Containers

Steel drums are manufactured using automated equipment and cost significantly less than custom fabricated steel containers on a unit volume basis. For cask shipments, the larger container fills the cask cavity more completely, which allows a larger quantity of waste to be shipped per shipment. For these reasons, the cost of container and transportation must be considered together.

Figure 4 shows the unit cost of containers and transportation for shipments ranging in distance from 250 to 2,500 miles.

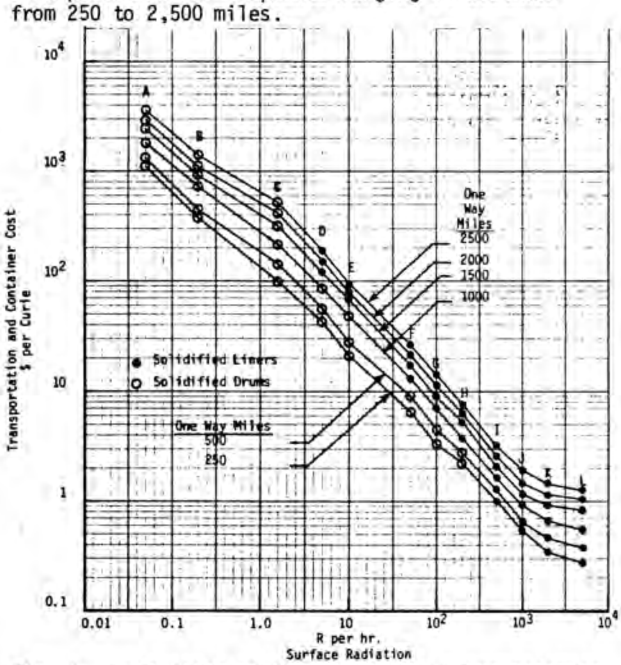

Fig. 4. Unit Costs of Containers and Transportation

The factors to be noted are as follows:

- o For unshielded and shielded van shipments, drums are more economical since the number of drums is not limited by the cask cavity.

- For shielded shipments of containers with radiation levels of 5 R per hour and greater, solidified liner shipments cost less than drums at distances of 1,500 miles or more.
- For shielded shipments of containers having radiation levels of 100-200 R per hour, solidified liner shipments are less expensive than drums for all distances greater than 250 miles.
- Solidification costs have not been included in this analysis. When solidification is performed within the containers themselves, the additional cost of the larger liners will generally be completely offset by the higher cost of solidifying drums.
- The unit costs of containers and transportation are reduced as the concentration of the waste is increased. At 10 R per hour, the cost of containers and transportation is less than $1.00 per curie even with one-way transportation distances up to 2,500 miles. With waste concentrated above 100 R per hour, the container and transportation costs can be less than 10¢ per curie.

Overall

Figure 5 shows the overall cost of containers, transportation and burial for solidified drums and large containers.

The factors to be noted are as follows:

- For unshielded shipments and shipments in shielded vans, drums are more economical (cost of solidification not included).
- For cask shipments, large containers are generally more economical or equal to drum shipments (even when the cost of solidification is excluded).

OTHER EVALUATIONS

As noted above, solidification can reduce the cost of low-level radioactive waste disposal. A further evaluation of the conditions under which solidification can be beneficial was made. In addition, an evaluation was made of the effects of holding waste to allow it to decay.

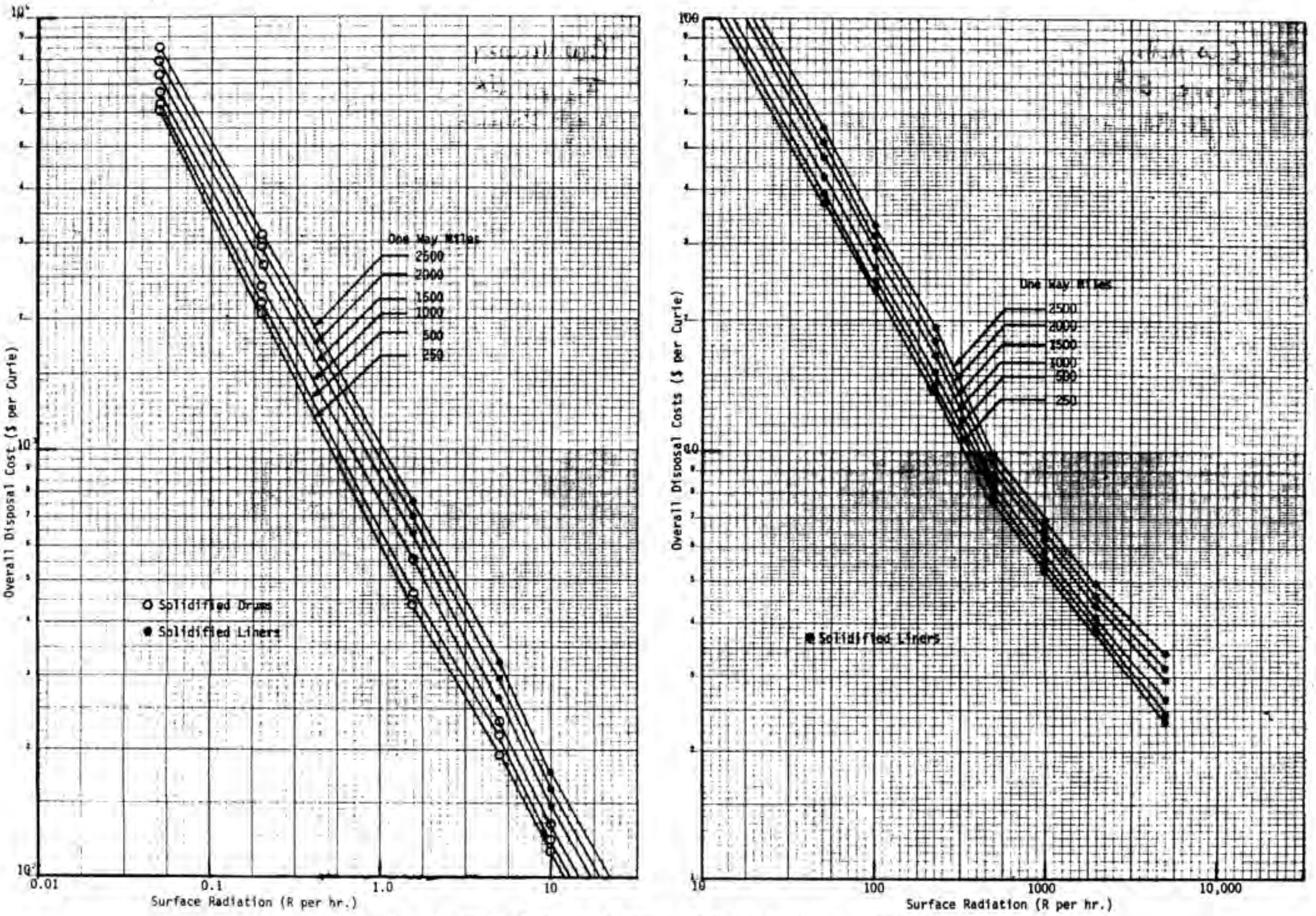

Fig. 5 Overall Disposal Costs for Solidified Liners and Drums

Effects of Solidification

Figure 3 indicates a significantly lower burial cost for solidified material than for dewatered material. This applies to containers having the same surface radiation levels. Table V contains an evaluation of the burial cost for resin having a specific activity of 100 μCi per ml. This evaluation compares dewatering and disposal in a large high integrity container with solidification and disposal in a large steel container.

TABLE V

EFFECTS OF SOLIDIFICATION

Assumptions

Specific Activity of Resin (μCi/ml)		100
Composition of Activity	Cobalt-58 (%)	25
	Cobalt-60 (%)	25
	Cesium-134 (%)	25
	Cesium-137 (%)	25
Surface Radiation Coefficients:		
Dewatered (R/hr. per μCi/ml)		1.254
Solidified (R/hr. per μCi/ml)		0.272
Burial Volume of Liners (CF)		100
High Integrity Container Net Volume (CF)		67
Steel Liner, Solidified Volume (CF)		90
Packing Efficiency (%)		55

High Integrity Container

Volume of Resin (CF)	67
Specific Activity (μCi/ml)	100
Surface Radiation (R/hr.)	125
Total Activity (Ci)	190
Burial Charges:	
Basic Burial Charge (100 x 14.50)	$1,450
Surcharges	
Radiation (80 CF x 100/CF)	8000
Weight (1000-5000 lbs.)	250
Curie Content (190 Ci)	4000
Cask Handling	500
Perpetuity Fund	250
S.C. Disposal Tax	400
Subtotal	14,850
Barnwell Co. Tax (@ 2.4%)	356
Total	$15,206
$ per curie ($15,206 ÷ 190)	$ 80.03

Solidified Liner

Packing Efficiency (%)	55
Specific Activity Before Solidification (μCi/ml)	100
Specific Activity After Solidification (μCi/ml)	55
Surface Radiation (55 x 0.272) R/hr.	15
Burial Volume of Liner (CF)	170
Solidified Volume (CF)	150
Resin Volume Before Solidification (CF) (0.55 x 150)	82.5
Total Activity (Ci) (82.5 x 100 x 28,317 ÷ 10^6)	234

TABLE V cont.

Burial Charges:	
Basic Charge (170 x $14.50/CF)	$ 2,465
Surcharges:	
Radiation (170 x $30/CF)	5,100
Weight (10,000-20,000)	1,000
Curie Content	4,000
Cask Handling	500
Perpetuity Escrow Fund	680
S.C. Disposal Tax	425
Subtotal	$14,170
Barnwell Co. Tax	340
Total	$14,510
$ per curie	62.01
$ per CF Resin	175.88

The following points are noted relative to comparison of solidification and dewatering of a specific waste:

- o The dilution by solidification and the self shielding due to solidification will materially reduce the surface radiation levels (125 R per liner reduced to 15 R per hour).
- o The lower surface radiation levels due to solidification will allow the use of higher volume liners and casks (170 CF vs. 100 CF).
- o The larger volume liner will allow more resin per shipment (82.5 CF vs. 67 CF) even with a low packaging efficiency (55%).
- o The lower surface radiation levels with solidified material reduce the radiation surcharge and make the overall burial cost less for the larger solidified containers.
- o The burial cost for the resin is reduced by $18 per curie or $50 per cubic foot with solidification.
- o The cost of solidifying waste is comparable to the difference in burial costs and must be included in the evaluation of waste solidification versus dewatering.

Effects of Aging and Decay

The analysis was based on having equal amounts of the following radionuclides:

Radioisotope	Half Life	Gamma Energy (Mev.)	Abundance (% x 100)
Cobalt-58	71.3d	0.511	0.30
		0.810	0.99
		0.865	0.014
		1.67	0.006
Cobalt-60	5.26y	1.17	1.00
		1.33	1.00
Cesium-134	2.05y	0.57	0.23
		0.605	0.98
		0.795	0.99
		1.038	1.00
		1.168	0.019
		1.365	0.034

Radioisotope	Half Life	Gamma Energy (Mev.)	Abundance (% x 100)
Cesium-137	30.2y	0.662	0.85

As indicated, this assumed waste composition includes radioisotopes with half lives of 71.3 days to 30.2 years. They are gamma emitters with the highest being Cobalt-60, which emits two gammas with energies of 1.17 and 1.33 Mev. per emission.

Figure 6 shows the surface radiation levels on the exterior of a container containing one microcurie per milliliter of dewatered waste composed equally of the four radionuclides listed above.

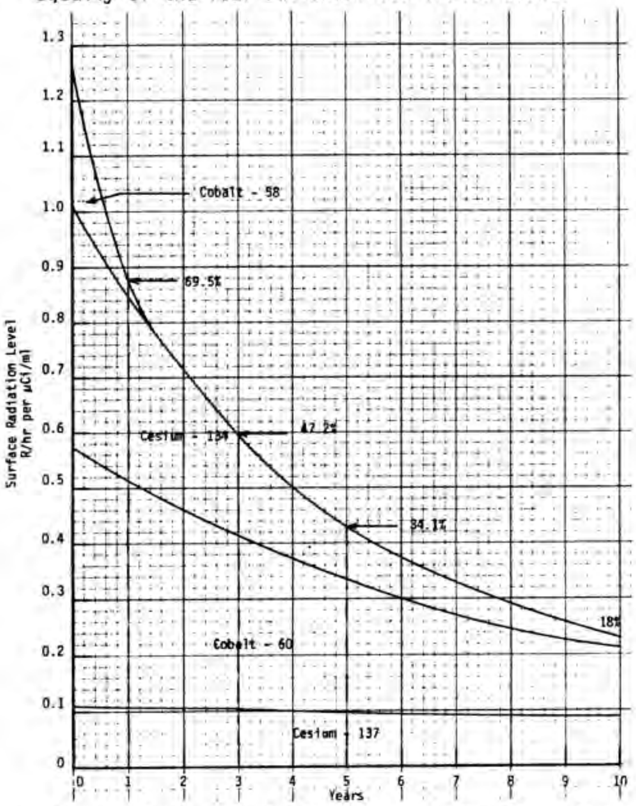

Fig. 6. Surface Radiation Levels as Function of Decay Time - Dewatered Material

At the end of one year, the surface radiation level will be reduced by 30.5 percent primarily due to the decay of Cobalt-58. At the end of five years, the radiation levels will be reduced by 65.9 percent. After five years, the Cobalt-58 will essentially be gone, the concentration of Cesium-134 will be reduced by over 75 percent and the Cobalt-60 will be reduced by nearly 50 percent.

The effects of solidification are dramatically portrayed in Figure 7. Figure 7 shows the radiation levels on the surface of a solidified container containing the same one microcurie per milliliter of radioactive material as shown in Figure 6. After solidification, the percentage reductions in radiation levels will occur at essentially the same rate as for dewatered material.

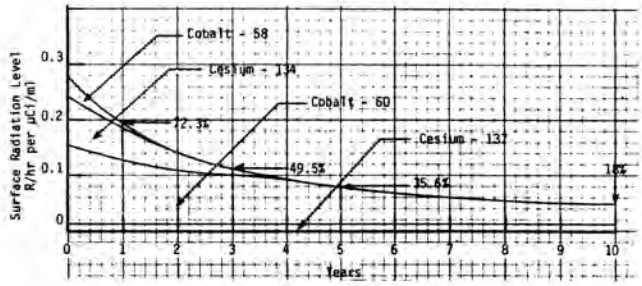

Fig. 7. Surface Radiation Levels as Function of Decay Time - Solidified Material

SUMMARY

Several significant findings were made in this evaluation. These include:

- Current burial schedules provide appreciably lower burial charges on a "per curie" basis for concentrated radioactive materials.
- Processing methods that increase the concentrations of radioactivity can be more beneficial than those which only reduce volume.
- For high concentrations of radioactivity, solidification will allow significantly higher concentrations and greater amounts of activity than dewatered materials with the same surface radiation levels. The higher amounts of activity will reduce the cost of disposal.
- Transportation and container costs are also significantly reduced on a "per curie" basis for concentrated radioactive waste shipments.
- The higher unit cost of custom fabricated containers is generally offset by the greater volume per cask shipment compared to steel drums.
- The highest cost shipments are actually unshielded and shielded van shipments where the unit costs are thousand of dollars per curie.
- With solidified waste packages having surface radiation levels greater than 100 R per hour, the overall disposal cost are less than $20 per curie.
- Allowing dewatered waste to decay for three years reduces the surface radiation levels by about 50 percent.
- Solidifying dewatered waste will reduce surface radiation levels by about 78 percent.

REFERENCE 1. C.W. Mallory, "Overall Effects of Reclassification of Low Specific Activity Radioactive Materials," Proceedings of the Symposium on Waste Management, Tucson, AZ, February 27 - March 3, 1983.