OPTIMIZATION OF TRANSPORTABLE ON-SITE STORAGE MODULES

Charles W. Mallory
Westinghouse Hittman Nuclear Incorporated
Columbia, MD 21045

ABSTRACT

Transportable on-site storage modules were evaluated in terms of handling the wastes generated by nuclear power plants. Modules having cavities of 54, 60 and 74 inches in diameter and constructed of ordinary, magnitite and ferrophosphorus concrete were used in the analysis. Radiation coefficients were derived and used with decay constants to select modules based on having external radiation levels of 10 mR per hour at two meters after storage. Cobalt-60 was found to have a dominant effect on the selection of the modules. Using the selected modules, the cost of preparing waste for storage was determined to be significantly lower than disposal in the traditional manner at the current disposal sites.

INTRODUCTION

Several years ago, the concept of concrete on-site storage modules for low-level radioactive waste was introduced. A number of power plants and other generators are now using these storage modules rather than the more conventional storage building with shielded storage cells and/or the capability of remote handling of waste. The unit cost of storage in on-site storage modules is generally less than the large storage facilities. The modules have relatively short delivery times and can be procured as they are needed to avoid having to commit to excess storage capacity.

In 1984, the concept of using concrete canisters to overpack waste packages for burial was introduced. In this concept, the waste packages are placed in the modules and grouted. The concrete canister provides structural stability and avoids subsidence due to deterioration of the waste containers, voids in the containers and compression of the waste. In some cases, the concrete canisters are cubes or hexagonal which allows them to be placed in a close packed array in the disposal trench. This avoids subsidence due to the settling and compaction of backfill.

In this paper, the concept of using the same modules for both storage and disposal is explored, with emphasis on the storage considerations. For the purpose of this evaluation, the hexagonal modules having the same external dimensions are assumed. The diameter and height of the cavities is decreased to provide additional shielding for the higher activity radioactive waste. In addition, three types of material are used for the construction of the modules to avoid having to unnecessarily reduce the capacity of the modules for the higher activity waste.

The modules are referred to as "Transportable On-Site Storage Packages" or "TOSSPAKs".

THE STORAGE MODULE

Figure 1 shows the configurations of the storage modules used in this evaluation. Table I shows the dimensions of the three cavity sizes. The 74 inch diameter corresponds to an array of seven 55-gallon drums stacked two high. The 60 inch cavity corresponds to a four drum array and the 54 inch cavity to a three drum array. If used for drums, additional

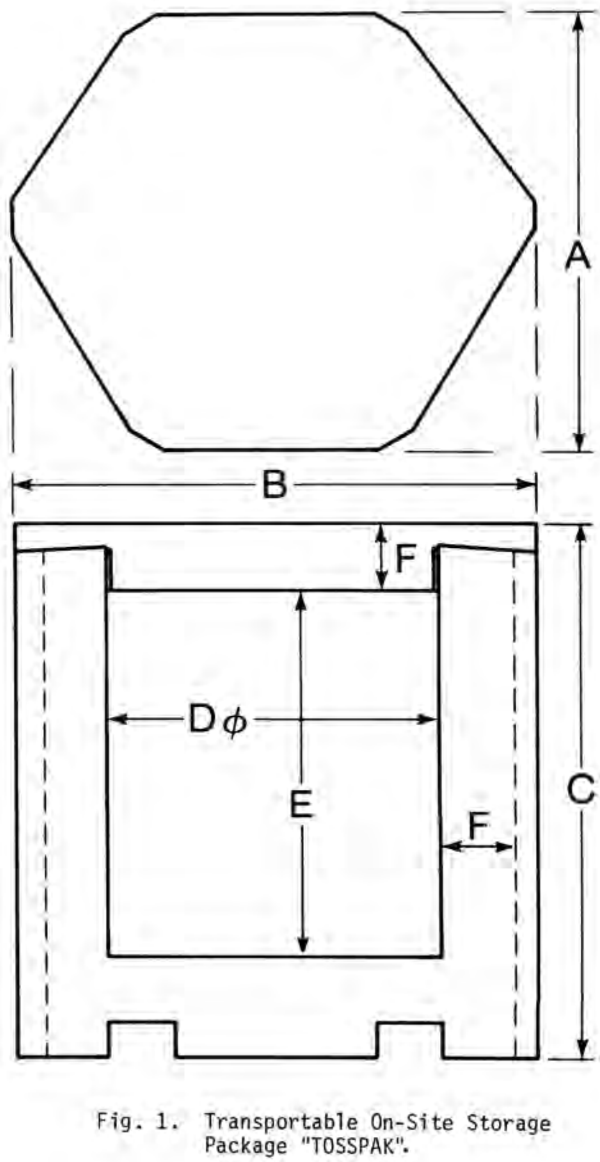

Fig. 1. Transportable On-Site Storage Package "TOSSPAK".

TABLE I

TOSSPAK Modules Dimensions

Dimension	Model Number TP200	TP110 (inches)	TP90
A	83	83	83
B	92	92	92
C	96	96	96
D	74	60	54
E	81	67	61
F*	4.5	11.5	14.5

*Minimum shield thickness

drums would be placed on their sides to give a capacity of six and four drums, respectively. However, the analysis presented in this paper is based on the waste being solidified directly in the storage module and utilization of the full capacity of the cavity.

As shown in Table II, three types of materials have been used for the construction of the storage modules. The "C" designation refers to modules constructed of ordinary concrete with a density of 147 pounds per cubic foot. The "M" refers to modules constructed using magnitite with a density of 218 pounds per cubic foot. The "F" refers to modules constructed using Ferrophosphorus as an aggregate to provide a density of 292 pounds per cubic foot.

TABLE II

TOSSPAK Modules Characteristics

Model Number	Type Concrete	Cavity Volume (CF)	Weight Empty (lbs)	Weight Loaded (lbs)
TP200C	Ordinary	200	20,520	40,680
TP200M	Magnetite	200	30,570	50,730
TP200F	Ferrophosphorus	200	40,872	61,030
TP110C	Ordinary	110	33,718	43,720
TP110M	Magnetite	110	50,232	61,232
TP110F	Ferrophosphorus	110	67,160	78,160
TP90F	Ferrophosphorus	90	73,460	82,460

Table II also shows the weight of the empty and loaded modules. The TP200C, TP200M and the TP110C would be transportable within the weight limits for interstate highways. The other modules would require overweight permits and the TP90F would probably be a restricted shipment.

WASTE CHARACTERISTICS

For the purposes of this evaluation, the waste characteristics for power plant wastes compiled by the Electric Power Research Institute were used (1). These were further consolidated into four waste types for pressurized water plants as shown in Table III. Table IV shows the consolidated waste types that were used for boiling water plant wastes. In all cases, the highest specific activities for the individual waste groupings were used.

It should be noted that the waste classifications developed by EPRI are for aged wastes. The majority of the short lived isotopes will have decayed and the isotopes shown will dictate the storage requirements over the one to fifty year time span.

The analysis can also apply to industrial and institutional wastes. Industrial and institutional waste will generally have specific activities than those shown as PWR-1 and BWR-1 waste.

TABLE III

Typical Power Plant Wastes Used for Analysis (Adapted from EPRI NP-3370)

Radio-Isotopes	Specific Activity (uCi per ml) Waste Types PWR-1	PWR-2	PWR-3	PWR-4
MN-54	4.45 E-3	1.02 E-2	4.32 E+0	1.03 E+2
CO-58	4.24 E-2	8.64 E-2	1.81 E+1	4.28 E+2
CO-60	5.93 E-2	6.61 E-2	2.16 E+1	5.14 E+2
CS-134	1.39 E-2	2.29 E-2	9.37 E+0	2.23 E+2
CS-137	2.97 E-2	5.09 E-2	1.58 E+1	3.77 E+2

PWR-1 Dry Active Waste, Compactible and Noncompactible

PWR-2 Concentrates, Chemical and Other Wastes

PWR-3 Resins, Spent Fuel, Liquid Radwaste, Other

PWR-4 Resins, Reactor Clean-up

TABLE IV

Typical BWR Power Plant Wastes Used for Analysis

Radio-Isotopes	Specific Activity uCi per ml Waste Types BWR-1	BWR-2	BWR-3
MN-54	1.17 E-3	4.59 E-1	1.8 E-1
CO-60	5.09 E-3	1.61 E+0	9.02 E+1
ZN-65	6.36 E-4	6.89 E-1	3.87 E+1
I-131	-	1.38 E-1	-
CS-134	8.48 E-4	9.64 E-1	3.09 E+1
CS-137	1.80 E-3	1.29 E+0	5.93 E+1

BWR-1 Dry Active Waste, Compactible and Noncompactible

BWR-2 Resins and Sludges, Condensate Polishing, Spent Fuel Pool, Liquid Radwaste

BWR-3 Resins and Sludges, Reactor Clean-up System

SHIELDING CAPABILITIES

Figure 2 shows the shielding characteristics of the various transportable on-site storage modules used in the analysis. These curves were derived using shielding characteristics of various shipping casks and interpolating the data using linear attenuation factors for the storage modules.

In order to estimate the external radiation attributable to each of the radionuclides, radiation coefficients were developed for each radioisotope and each storage container. The radiation coefficients were derived using a technique previously presented in Ref. 2 and 3. With this technique, the external radiation attributable to each gamma emission is calculated as the product of the external radiation and the fractional abundance of the individual gamma emissions. Table V shows the radiation coefficients for four of the storage modules and the radionuclides identified in the various waste sources. The analysis was performed using the radiation levels at two meters from the storage modules. This was done to determine when the storage modules would have decayed to 10 mR per hour at two meters and could be shipped to a disposal facility. For containers of this size, the contact radiation levels on the side of the containers will be approximately five times the radiation levels at two meters.

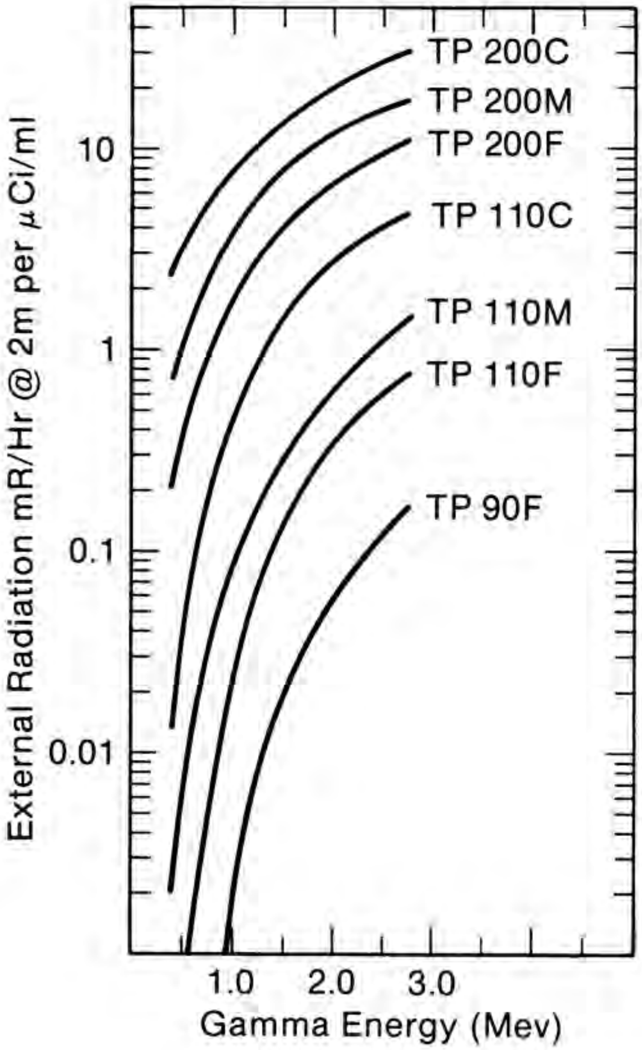

Fig. 2. External Radiation as a Function of Gamma Energy.

TABLE V

Typical Radiation Coefficients
mR/hrs @ 2m per uCi/ml

Isotope	TP200C	TP200M	TP110C	TP110M
MH-54	5.85	2.545	0.235	0.0426
CO-58	7.4034	3.149	0.285	0.0519
CO-60	20.533	11.103	1.678	0.328
ZN-65	4.291	2.228	0.295	0.0558
I-131	0.359	0.140	0.00886	0.00163
CS-134	10.521	4.283	0.364	0.0614
CS-137	3.619	1.401	0.0931	0.0163

It was assumed that all of the waste was solidified with cement and with a packaging efficiency of eighty percent. The decay constants for each of the radionuclides were then used to calculate the specific activity of each radionuclide after three and six months and after one, three, five, ten, twenty, and fifty years. The external radiation levels were computed by summing the products of the specific activities and the radiation coefficients for each radionuclide.

Low Activity Waste

It was found that the largest transportable onsite storage module with the thinnest (4.5 inch) wall of ordinary concrete would be adequate to shield the dry active waste generated by power plants. As shown in Table VI, the external radiation levels will be less than 2 mR per hour at two meters for the dry active waste having the highest specific activity.

TABLE VI

Low Activity Waste
Packaged in TP200C

Waste Type	External Radiation* mR/hr @ 2m	Specific Activity* uCi/ml	Total Activity Ci
PWR-1	1.45	0.12	0.67
PWR-2	1.99	0.19	1.07
BWR-1	0.166	0.614	0.078

*After solidification.

Industrial and institutional waste would have specific activities comparible to the dry active waste generated by power plants. These wastes could also be packaged and stored in the TP200C modules with low external radiation levels.

Intermediate Activity Waste

Table VII illustrates the effects of radioactive decay on the selection of storage modules. In the case of the PWR-3 waste it could be packaged in a TP110M container and shipped immediately. The PWR-3 waste could also be packaged in the TP110C container. In this case, the external radiation level would be about 38 mR per hour at two meters. However, this would reduce to about 9 mR per hour at two meters after ten years of storage and would then be shippable. The advantage in this case would be the use of a less expensive module.

TABLE VII

Intermediate Activity Waste

Waste Type TOSSPAK	PWR-3 TP110C	PWR-3 TP110M	BWR-2 TP200C	BWR-2 TP200M
Radiation (mR/hr @ 2m)				
Initial	37.8	7.2	42.8	21.2
At 5 yrs.	16.6	3.2	18.5	9.3
At 10 yrs.	8.8	1.7	10.3	4.2
At 20 yrs.	2.8	0.5	4.3	1.9
Activity (Curies)				
Initial	172.4	172.4	23.4	23.4
At 5 yrs.	68.4	68.4	10.1	10.1
At 10 yrs.	46.5	46.5	6.7	6.7
At 20 yrs.	28.8	28.8	4.2	4.2

In the case of the BWR-2 waste, the choice of containers is dictated by the allowable storage time. The less expensive container can be used if the material is to remain in storage for ten years rather than five years.

High Activity Waste

Table VIII shows that the transportable on-site storage modules are capable of handling the high activity waste generated by nuclear power plants. This table also illustrates how storage and radioactive decay effect the selection of storage modules. In the case of the PWR-4 waste, a TP90F module would allow the waste to be packaged for immediate shipment. However, if the waste is to remain in storage for slightly over ten years, a larger and less expensive storage module can be used.

TABLE VIII

High Activity Waste

Waste Type TOSSPAK	PWR-4 TP-110F	PWR-4 TP-90F	BWR-3 TP-110M	BWR-3 TP-110F
Radiation (mR/hr @ 2m)				
Initial	61.5	6.51	27.74	9.7
At 5 yrs.	26.9	3.15	13.23	4.64
At 10 yrs.	14.6	1.64	7.00	2.43
At 20 yrs.	4.0	0.46	2.19	0.69
Activity (Curies)				
Initial	4100	3354	546	546
At 5 yrs.	1603	1311	263	263
At 10 yrs.	982	907	178	178
At 20 yrs.	686	561	110	110

In the case of the BWR-3 waste, a less expensive container can be used if the waste is to be stored for ten years.

DOMINATING FACTORS

In the performance of this analysis, it was apparent that the external radiation levels for most of the waste types were dominated by the presence of Cobalt-60. This is illustrated in Fig. 3. Because of the two hard gammas emitted by Cobalt-60 (i.e., 1.17 and 1.33 Mev) and the large fractional abundance of these emissions (i.e., 100%), the radiation coefficients for Cobalt-60 are higher than all of the other radionuclides (see Table V). Cobalt-60 also has a relative long half life (i.e., 5.26 years) which causes it to be a major contributor over the first 30 years of storage. The external radiation due to the other radionuclides (i.e., MN-54, Co-58, ZN-65, CS-134) is a factor only for the first three years of storage.

After 30 years of storage, Cesium-137 becomes the dominant remaining radionuclide. The external radiation due to Cesium-137 is low because of the low gamma energy (0.662 Mev) and the relatively low fractional abundance (i.e., 85%). As a result, the external radiation levels after 50 years of storage are less than four percent of the initial values.

ECONOMIC FACTORS

The cost of the transportable on-site storage packages will be strongly influenced by the number of modules used. Ideally, the modules would be fabricated locally by firms specializing in the fabrication of prefabricated concrete products. The forms would be shipped to the fabricators rather than ship the finished products. Table IX shows the probable range in cost for the modules when produced in lots of ten.

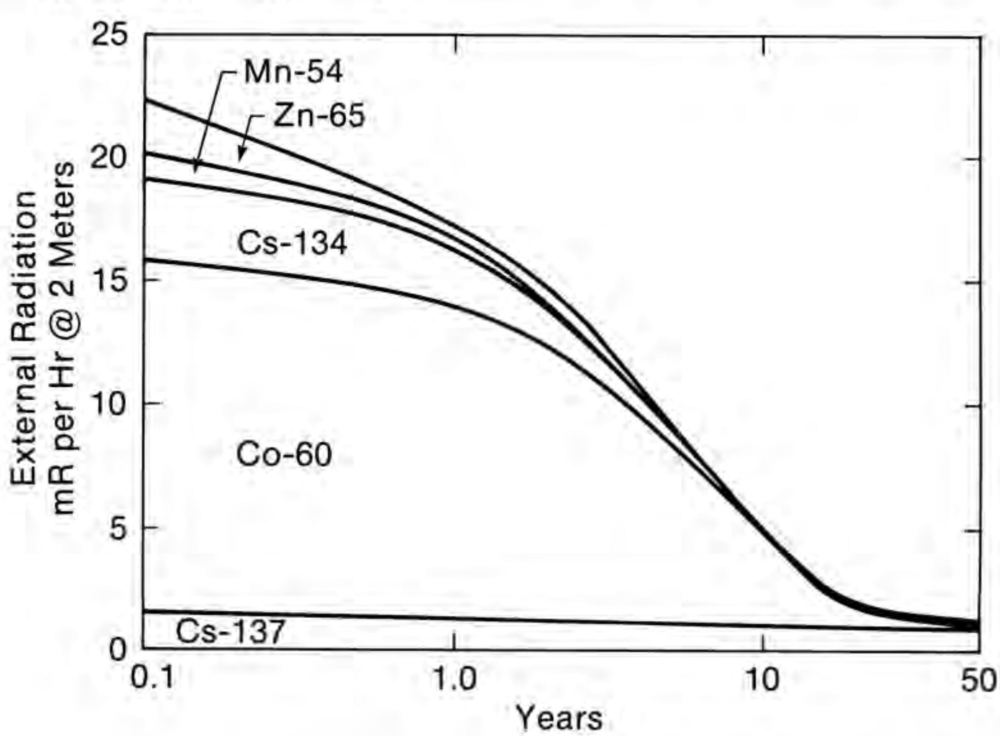

Fig. 3. External Radiation Levels as a Function of Time and Radionuclide.

TABLE IX

Typical Module Costs

Model No.	Cost
TP-200C	$ 2,500
TP-200M	$ 4,500
TP-200F	$ 7,500
TP-110C	$ 3,500
TP-110M	$ 6,500
TP-110F	$11,500
TP-90F	$12,500

Table X shows the parameters involved in the storage of BWR-2 waste in two types of storage modules. Table XI shows the cost of preparing the modules for storage.

TABLE X

Storage Parameters

Waste Type:	BWR-2	BWR-2
TOSSPAK Model:	TP-200C	TP-200M
Storage Time:	10 years	5 years
Radiation Levels (mR/hr)		
Initial		
Side Contact	200	100
Side @ 2m	43	21
After Storage		
Side Contact	50	50
Side @ 2m	10	10
Activity (Curies)		
Initial	23.4	23.4
At 5 years	10.1	10.1
At 10 years	6.7	6.7

TABLE XI

TOSSPAK Storage Costs

Waste Type:	BWR-2	BWR-2
TOSSPAK Model:	TP-200C	TP-200M
Storage Time:	10 years	5 years
Typical Costs:		
TOSSPAK Module	$ 2,500	$ 4,500
Processing	$ 1,500	$ 1,500
Total	$ 4,000	$ 6,000
Unit Costs		
$ per CF	$ 20.00	$ 30.00
$ per Curie	$ 170.94	$ 256.41

For comparative purposes, Table XII shows the parameters involved in the disposal of the PWR-2 waste. Table XIII shows the current costs of disposing of this waste in the traditional manner.

Comparing Tables XI and XIII, illustrates the benefits that could accrue to a state or compact by storing their waste until a disposal site becomes available.

TABLE XII

Disposal Parameters

Waste Type:	BWR-2
Waste Volume:	200 CF
Waste Weight:	20,000 lbs.
Liner Weight:	1,500 lbs.
Total Weight:	21,500 lbs.
Activity:	23.4 Ci

TABLE XIII

Disposal Costs

Waste Type:	BWR-2
Preparation:	
Disposable Liner	$ 2,500
Processing	$ 1,500
Total Preparation	$ 4,000
Burial:	
Volume Charge	$ 6,300
Curie Surcharge	$ 3,750
Weight Surcharge	$ 1,310
Cask Handling	$ 800
Local Tax	$ 290
Total Burial	$12,450
Compact Surcharge	$ 2,000 (1)
Total Disposal	$18,450
$ per CF	$ 92.25
$ per Cuire	$ 788.46

(1) Non-sited states 1987-1988.

SUMMARY

From this evaluation, it has been concluded that the same modules can be used for storage and disposal. However, it remains to be shown that a concrete module with impact protection can be qualified as a shipping container for Type A and greater than Type A quantities of Low Specific Activity radioactive material. Under current shipping regulations, the PWR-4 waste would not be L.S.A. and would require a Type B certification.

Radioactive decay allows the storage modules to be loaded to higher radiation levels than would be allowable for shipping. During storage, the external radiation levels will decrease to levels acceptable for shipment. The concept of using smaller diameter cavities and available heavy aggregate concrete will accommodate the waste generated by nuclear power plants as well as institutional and industrial generators.

The Cobalt-60 contained in the waste is the dominant contributor to the external radiation and dictates the selection of the storage modules. The other radionuclides initial contribute about 30 percent to the external radiation. After three years, Cobalt-60 is about 85 percent of the external radiation levels. After 30 years, the Cobalt-60 decays to comparable radiation levels to the Cesium-137 and after 50 years Cesium-137 is the sole remaining contributor to external radiation. After 50 years, the external radiation levels are less than four percent of the levels after initial packaging.

Radioactive waste can be placed into modules for storage at a much lower cost than disposing of the material at the present disposal sites. States and non-sited Compacts can potentially save significant amounts of money by storing waste until disposal sites become available.

REFERENCES

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