COMPARISON OF PREDICTED VERSUS MEASURED DOSE RATES FOR LOW-LEVEL RADIOACTIVE WASTE CASK SHIPMENTS

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ABSTRACT

Shippers of low-level radioactive waste must select casks which will provide sufficient shielding to keep dose rates below the federal limit of 10 mr/hr at 2 meters from the vehicle. Chem-Nuclear Systems, Inc. uses a cask selection methodology which is based on shielding analysis code predictions with an additional factor of safety applied to compensate for inhomogeneities in the waste, uncertainties in waste characterization, and inaccuracy in the calculational methods. This proven cask selection methodology is explained and suggested factors of safety are presented based on comparisons of predicted and measured dose rates. A safety factor of 2 is shown to be generally appropriate for relatively homogeneous waste and a safety factor of between 3 and 4 is shown to be generally appropriate for relatively inhomogeneous wastes.

INTRODUCTION

Selection of a shipping cask for low-level radioactive waste from a shielding standpoint must balance two considerations: (1) the federal requirement to keep dose rates below the federal limit of 10 mr/hr at 2 meters from the vehicle carrying the cask, and (2) not using unnecessary shielding which incurs the cask user additional costs. Cask users can consult shielding curves which have been developed by cask suppliers to assist in selection of the appropriate cask based on the waste source. Use of the shielding curves is a simple, effective method for cask selection for most shipments. However, use of shielding analysis programs is the preferred method when the waste characteristics do not conform to those assumed in developing the curves, when the waste fills only a small portion of the cask, or for borderline situations.

Specifically analyzing a particular shipment using a computer model was generally cost prohibitive until the advent of personal computers with user-friendly programs. User-friendly shielding analysis programs running on personal computers make analysis of particular waste shipments feasible for cask suppliers and users alike.

Cask suppliers have developed user-friendly in-house shielding programs for cask selection based on results of more complex programs such as transport-theory programs. Chem-Nuclear's program CASC (Choose A Shipping Cask) is based on ANISN results while Westinghouse Hittman Nuclear Incorporated developed its program MaxPak based on SPAN-4 results (1). Microshield (2) is an example of a user-friendly commercially available shielding program used by cask users and suppliers alike. Each of these programs predicts dose rates based on shielding theory. The theoretical predictions must be multiplied by safety factors to compensate for such real life factors as inhomogeneities in the waste, isotopic sampling error, nonuniformities in cask geometry, and inherent error in the calculational methods.

CASK SELECTION METHODOLOGY

Cask Shielding Curves

The first step in selecting a cask based on shielding requirements is to compare the waste characteristics with shielding curves for casks provided by the cask supplier. Chem-Nuclear's cask shielding curves express either maximum permissible total activity concentration or maximum permissible liner dose rate as a function of Co-60 percent of total activity within the waste. These curves, which were generated using Chem-Nuclear's CASC program, may be obtained from Chem-Nuclear's Marketing Department. Chem-Nuclear's shielding curves apply a safety factor of 2 to the theoretical (CASC-predicted) dose rates.

If the waste meets the assumptions inherent in the curves, then the curves generally provide a simple and effective method for selecting a cask. Key assumptions inherent in the curves are

- the waste is relatively homogeneous
- the waste is either dewatered resin with a density of 0.6 g/cc or concreted waste with a density of 2.0 g/cc (depending on the particular curve)
- non-Co-60 isotopes emit on the average one 1.0-Mev gamma per disintegration
- the waste fills the interior of the cask

When Cask Shielding Curves Don't Apply

If the waste deviates significantly from the any of the above assumptions, then a computer model of the proposed shipping configuration is called for. Examples of waste evaluations benefiting from computer modeling are wastes having very non-uniform liner doses, wastes consisting of dewatered filters or activated metals, or wastes containing a high fraction of total activity due to isotopes (other than Co-60) with energies much different than 1.0 Mev. The isotope Fe-55, a very low-energy gamma emitter, is an example of an isotope whose gammas differ greatly from the 1.0 Mev assumption.

Computer Modeling

When computer modeling is called for Chem-Nuclear Systems, Inc. generally creates two independent computer models: one using the proprietary CASC program and the other using the commercial program Microshield. Experience shows that the two models give very close agreement with each other. The purpose of creating two independent models and comparing their results is to verify that each model has been created correctly. That is, if the results of the models differ significantly, then the models are carefully rechecked for input or modeling errors.

The following information is generally input into the computer models

- waste material composition
- waste isotopic composition

- liner dimensions
- cask dimensions and materials

The computer programs predict dose rates at 2 meters *from the* cask based on the above information and parameters built-into the programs themselves. If the measured *maximum* liner dose rate is known, then predicted dose rates at 2 meters from the vehicle are next multiplied by the ratio of maximum measured liner dose rate to predicted liner dose rate. This normalization to measured liner dose rate increases the accuracy of the prediction at 2 meters from the vehicle because it compensates for waste inhomogeneity.

Generally, dose rates are not calculated at the cask surface since experience has shown that cask surface dose rates are well below the 200 mr/hr federal cask surface dose rate limit whenever the 10 mr/hr limit at 2 meters from the vehicle is met. Typically, dose rates on the cask surface are between 60 mr/hr and 80 mr/hr when the 2-meter dose rate is 10 mr/hr.

Need for Safety Factors

The calculated dose rates at 2 meters from the vehicle do not account for inhomogeneities in the waste, uncertainties in the isotopic sampling process, deviations in cask wall thickness, inherent inaccuracies in the computer programs, or other real life factors. Thus, a safety factor must be applied to the prediction before the predicted dose rates can be used to select a cask. This safety factor is sometimes referred to as a "peak-to-average factor" because waste inhomogeneities are thought to be the primary contributor to the disagreement between measurement and predictions.

Development of Safety Factors

Chem-Nuclear Systems, Inc. compared, during 1985, dose rate predictions from CASC models of 51 actual shipments with measured dose rates. This effort was part of an in-house project to verify methods used to produce shielding curves for each Chem-Nuclear cask. Isotopic concentrations were read from Radioactive Shipment Manifest (RSM) forms and input to CASC. Measured dose rates were obtained from the RSM's and compared with the CASC predictions. The study assumed that the ratio of measured-to-predicted dose rates could be approximated by a Gaussian distribution.

Dose rates reported on the RSM's at the liner surface are typical dose rates rather than maximum dose rates. In contrast, dose rates measured at the cask outside surface and at 2 meters from the cask are maximum dose rates at these distances from the cask centerline.

The study found that the mean dose rate ratio (ratio of measured-to-predicted dose rates) at the liner surface was 1.15 and showed that the range of the mean of the parent population encompassed 1.0 at a 90% confidence level. Thus, the predictions showed good agreement with measurement on *the liner* surface. No significant bias, either high or low, was observed. This was expected since the "typical" liner dose rates are probably on the average close to the average liner dose rate.

The study found that the mean dose rate ratio at the cask surface was 1.68. Thus, on average the measured dose rates were higher than the predicted dose rates. This is expected since the measured dose rates are maximum dose rates while the predicted dose rates are average dose rates. The study showed that these same factors could be applied to the 2-meter dose rates as well as to the cask surface dose rates.

Statistical analysis showed that one could say with 60% certainty that the ratio will be 1.95 or less and with 95% certainty that it will be 3.45 or less. Based on this comparison, Chem-Nuclear generally applies a safety or peaking factor of 2 to calculated dose rates if the waste is relatively homogeneous and a factor of between 3 and 4 if the waste is relatively inhomogeneous.

EFFECTIVENESS OF THE METHOD IN ACTUAL SHIPMENTS

Comparison of Actual Shipments With Predictions

Chem-Nuclear assists its cask users by predicting 2-meter dose rates for shipments which do not meet the assumptions inherent in the cask shielding curves or which have some other idiosyncracy. These analyses are reviewed internally and maintained as engineering design reports.

To determine the effectiveness of the cask selection method and to confirm the earlier in-house study dose rate predictions are compared with measured dose rates from RSM's. It was only possible to locate 11 RSM's corresponding to predictions made in engineering design reports. While this number is not enough to perform a meaningful statistical analysis, it is enough to investigate whether there are any obvious flaws in the dose rate prediction methodology. These comparisons are shown in Table I. The waste type in each case is either dewatered resin or filter media.

Liner Dose Rates

Table I shows that on average the calculation method slightly overpredicts the liner dose rate. There is considerable scatter in the ratio of measured-to-predicted dose rates on the liner surface. If a safety factor of 2 were applied to the predicted liner dose rates, none of the predictions would exceed the measured value. In only 2 of the 11 cases would a safety factor greater than 1.05 be necessary to obtain agreement.

2 Meter Dose Rates Based on Isotopics

Table I compares two sets of predicted dose rates with measured dose rates at 2 meters from the cask. One set is predicted based on source isotopics while the other set of predictions equals the first set multiplied by the ratio of measured-to-predicted dose rate at the liner surface.

Predictions based on the source only are on the average greater than the measured dose rates. This is opposite the finding of the earlier study. It also is the opposite of expectations since predicted dose rates are average values while measured dose rates are maximum values. This comparison confirms that a safety factor of 2 is adequate for relatively homogeneous mixtures because none of the ratios exceed 2.

2 Meter Dose Rates Based on Isotopics and Measured Liner Dose Rates

The second set of comparisons at 2 meters from the vehicle shows that the method on the average slightly underpredicts dose rates when they are normalized to measured liner dose rates. More scatter is seen in this set of data than in the first set. This might seem to indicate that normalizing dose rate predictions to the maximum measured liner dose rate decreases the accuracy of the predictions. However, this is not the correct conclusion since the measured liner dose rates reported in Table I are generally typical liner dose rates rather than maximum liner dose rates. It does seem to show that if only a typical liner dose rate is known, and the maximum is

TABLE I

Comparison of Predicted Versus Actual Dose Rates (Without Safety Factors)

Doc. ID	Burial Date	Code(s) Used	Cask Type	Liner Surface (R/hr)			2 M From Vehicle (mr/hr) Based on Source Only			2 M From Vehicle (mr/hr) Normalized to Meas. Liner Dose Rate		
				Predicted	Measured	Ratio	Predicted	Measured	Ratio	Predicted	Measured	Ratio
NU-040	08/22/86	CASC	14-190	58	60	1.03	3.7	2	0.54	3.8	2	0.53
NU-086	10/24/88	Both	14-195 with P.B.	25.7	20	0.78	5.7	3	0.53	4.5	3	0.67
NU-088	12/14/88	CASC	14-195	2.5	2.5	1.00	1.5	2	1.33	1.5	2	1.33
NU-104	06/12/89	CASC	14-190 with P.B.	238	80	0.34	4.8	1	0.21	1.6	1	0.63
NU-106	09/07/89	CASC	14-190	285	100	0.35	3.1	4	1.29	1.1	4	3.64
NU-132	04/10/90	CASC	14-195	11.1	7	0.63	5.1	6	1.18	3.2	6	1.88
NU-145	08/23/90	Both	14-190 with P.B.	31	10	0.32	2	1	0.50	0.65	1	1.54
NU-155	11/08/90	Both	14-190	51.4	90	1.75	3.2	1	0.31	5.5	1	0.18
NU-176	05/10/91	Both	14-195	52	100	1.92	3.3	3	0.91	6.8	3	0.44
NU-180	05/07/91	Both	14-215 with P.B.	17	10	0.59	4.2	2.5	0.60	2.6	2.5	0.96
Average:						0.87			0.74			1.18

Notes:

(1) "Both" codes indicates that both CASC and Microshield calculated dose rate predictions. The average of the two codes is reported.

(2) "P.B." indicates that a personnel barrier was used with the cask.

(3) "Ratio" is the ratio of measured-to-predicted dose rates.

(4) Most of the measured liner dose rates reported in this table are typical rather than maximum dose rates. All of the measured dose rates at 2 meters from the vehicle are maximum values.

(5) "Normalized" indicates that the predicted 2-meter dose rate was multiplied by the ratio of measured-to-predicted dose rates at the liner surface.

not known, then normalizing to liner dose rate may not result in better dose rate predictions at 2 meters from the vehicle.

The comparison of normalized dose rates with measurements shows that a safety factor of 2 would be adequate in 10 of the 11 cases to make the predicted dose rates equal to or greater than measured dose rates. In one case a safety factor of 3.6 would be needed to achieve agreement. These findings confirm the practice of using a safety factor of 2 for relatively homogeneous mixtures and a factor of 3 to 4 for relatively inhomogeneous mixtures.

Benchmark Problem

Measured dose rates reported in Table I are taken from RSM forms which accompany each shipment of waste. GPU Nuclear Corporation (Mr. Richard Hurley) provided, for the shipment analyzed in NU-180, a much more detailed set of dose rate measurements than is shown on a RSM (3). Table II shows that dose rates on both sides of the vehicle are nearly the same. This indicates that the waste was probably relatively homogeneous. Table II compares predicted and measured dose rates for this benchmark problem.

The data supplied did not distinguish between liner dose rates on the passenger and driver's sides, but merely stated a range of 7 to 10 R/hr. Calculations which were normalized to measured dose rate were multiplied by the ratio of the maximum measured liner dose rate, 10 R/hr, to dose rate calculated from the source isotopics. Table II shows that the CASC and Microshield predictions are in close agreement with each other.

Results in Table II support the assertion that normalizing the predicted dose rates to measured liner dose rate increases the accuracy of the predicted dose rate at 2 meters from the vehicle. The average measured dose rate at 2 meters and the average calculated, normalized dose rate at 2 meters show an insignificant difference. In contrast, the average 2 meter dose rate based on only the source is 1.7 times the corresponding measured dose rate.

The average predicted, normalized dose rate on the cask surface, 40 mr/hr, equals 57% of the corresponding measured dose rate, 70 mr/hr. The cause for this disagreement is not known, but it could possibly be due to localized regions of the cask wall being thinner than average.

CONCLUSION

Shielding curves provided by shipping cask suppliers enable cask users to quickly select the appropriate cask based on shielding considerations. Those shipments not meeting the assumptions inherent in the shielding curves can be effectively analyzed using user-friendly PC-based programs such as the commercial program Microshield or proprietary programs written by cask suppliers. Dose rates calculated by these programs must be multiplied by a safety factor to account for inhomogeneities in the waste, uncertainties in the isotopic sampling, geometric variations in the casks, and inherent inaccuracies within the programs. Comparisons of predicted and measured dose rates indicate that a safety factor of 2 is generally appropriate for relatively homogeneous waste and a safety factor of between 3 and 4 is generally appropriate for inhomogeneous wastes. Accuracy of predicted dose rate at 2 meters from the cask can be improved if the predicted dose rate is multiplied by the ratio of measured liner dose rate to predicted liner dose rate.

REFERENCES

1. C. W. MALLORY, "Selection of Shipping Casks for Heterogeneous Radwaste," Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2-6, 1986 (1986).
2. "Microshield Version 3," Grove Engineering, Inc., Rockville, MD (1988).
3. R. HURLEY, "Documentation for Shipment ID Number 0491-229," private communication, GPU Nuclear -- Oyster Creek Station, Forked River, NJ (1991).

TABLE II

Benchmark Comparison of Predicted Versus Measured Dose Rates
(Without Safety Factors)

	Liner Surface (R/hr)	Cask Surface (mr/hr)	2 Meters From Vehicle (mr/hr)
MEASURED DOSE RATES			
Passenger Side		80	2.5
Driver's Side		60	2.5
Average	7 - 10	70	2.5
CALCULATED DOSE RATES			
CASC (normalized)	10	38	2.3
CASC (source only)	18	68	4.1
Microshield (norm.)	10	41	2.9
Microshield (source)	15	61	4.3
Average (norm.)	10	40	2.6
Average (source)	17	65	4.2