POTENTIAL IMPLICATIONS OF NON-RANDOM WASTE EMPLACEMENT ON PERFORMANCE ASSESSMENT FOR THE FIRST RECERTIFICATION OF WIPP

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP), a repository for defense transuranic (TRU) waste, was built and is operated by the US Department of Energy (DOE). The WIPP Land Withdrawal Act (LWA) required initial certification of compliance of the WIPP by the U.S. Environmental Protection Agency (EPA). In addition, a recertification decision is required by the LWA every five years, dated from the initial receipt of TRU waste. The first TRU waste shipment arrived at the WIPP on March 26, 1999, and therefore the first recertification application is due from DOE to EPA by March 25, 2004.

In an August 2002 letter, the EPA provided guidance to DOE concerning the necessity of incorporating an analysis of non-random waste emplacement into performance assessment during recertification: “The CRA should include a comparison of the effects of random and non-random emplacement of waste on releases given current emplacement practices and projected emplacement schedules.” The Environmental Evaluation Group (EEG), in its role of providing technical oversight of the WIPP project on behalf of the State of New Mexico, proceeded with its own analysis of emplacement data in order to provide recommendations to DOE.

Using waste emplacement data available from Panel 1, EEG’s analysis included: 1) comparison of emplaced activity for Panel 1 with the projected average activity for a fully-filled repository, 2) analysis of the effects of random versus non-random emplacement on vertical stacking of waste containers, and 3) analysis of volume/variance implications on the bounding analysis used during the initial certification.

Panel 1 was closed in March 2003. The degree of deviation between actual emplaced waste in Panel 1 and an assumption of random emplacement is apparent with concentrations of ^{239}Pu being 3.20 times, ^{240}Pu being 2.67 times, and ^{241}Am being 4.13 times the projected repository average for the space occupied by the waste.

The effect of non-random waste emplacement on the vertical stacking of waste containers was demonstrated by a comparison of the distribution of actual vertical stacks of waste with a distribution of stacks resulting from a randomization of the same waste. In the event of a future drilling intrusion, comparison of these two distributions shows a higher probability of intersecting a high-concentration stack of the actual emplaced waste, over that of the same waste emplaced in a randomized manner as was assumed in the certified performance assessment calculations. This suggests that the methodology used during the certification performance assessment calculations underestimated potential releases by cuttings and cavings. That

methodology sampled each layer in a stack and used the mean concentration for each waste stream.

A spallings release bounding analysis was performed at the time of the initial certification. The selection of the statistical sample size for this analysis assumed independence of samples, appropriate for a random emplacement assumption but not for non-random emplacement. Therefore, performance assessment should incorporate a sampling methodology for spallings which incorporates non-random emplacement or a bounding calculation using spatial statistical techniques.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), built and operated by the US Department of Energy (DOE), serves as a geologic repository for disposal of defense transuranic (TRU) waste. A recertification decision by the Environmental Protection Agency (EPA) is required by the Land Withdrawal Act at five year intervals, dating from the initial receipt of waste [1]. The first recertification application is due to the EPA from the DOE by March 2004.

The Environmental Evaluation Group (EEG), in its role of providing independent technical oversight of the WIPP project on behalf of the State of New Mexico, previously identified ongoing issues relevant to the first recertification performance assessment calculations [2]. One of these issues concerned the assumption of random emplacement of waste, used in the performance assessment conducted for the initial certification application [3]. As of now, waste emplacement has finished in Panel 1 and is currently being emplaced in Panel 2 of the WIPP. Operational experience confirms non-random emplacement versus random emplacement of waste.

In addition to the EEG's identification of the issue, the EPA also provided guidance to the DOE concerning the consideration of non-random emplacement. In an August 2002 letter, the EPA stated, "The CRA (Compliance Recertification Application) should include a comparison of the effects of random and non-random emplacement of wastes on releases given current emplacement practices and projected emplacement schedules" [4]. Toward this end, the EEG proceeded with an independent analysis of emplaced waste to provide a basis for technical review of the upcoming DOE analysis and to provide recommendations to the DOE for incorporation into performance assessment [5].

Panel 1 was closed in March 2003. Using all emplaced waste data from this panel, the EEG performed an analysis of the effects of non-random emplacement. This included: 1) comparison of emplaced activity for Panel 1 with the average activity, 2) analysis of the effects of random versus non-random emplacement on vertical stacking of waste containers, and 3) analysis of volume/variance implications on the DOE bounding analysis used for determination of spallings releases in the initial certification application.

The spatial distribution of waste in the repository is an issue for compliance because of the possibility of future human intrusions during the 10,000 year regulatory period. The WIPP is located in an area rich in oil, gas, and potash reserves [6]. Performance assessment calculations include intrusion scenarios involving drilling into the repository which results in solids released due to cuttings, cavings, and spallings [3]. Each intrusion is assumed to penetrate each container within a particular stack. For cuttings and cavings, it was assumed in the initial certification performance assessment that potential radioactivity which may be released into the environment can come from different waste streams, each having different amounts of activity at the time of the intrusion. This was accomplished by sampling the distribution of waste stream activity three times, once for each layer of waste in the stack, weighted by the waste stream volumes and averaging to determine the released activity. Therefore, there was no correlation between layers of waste, which is inconsistent with the manner in which waste arrives and is actually emplaced.

A spallings release, which results from a pressurized repository, may be much larger. The initial certification performance assessment assumed that a spallings event would release material from multiple drums and multiple waste streams and could be approximated by the average activity of all contact-handled waste. This is essentially an assumption of a homogenous distribution of radionuclides throughout the repository. It was calculated that the material removed by a spallings release would be between two and nineteen times the internal volume of a 55-gallon drum.

ANALYSIS OF WASTE EMPLACEMENT DATA

The EEG analysis of waste emplacement data included:

1) Comparison of emplaced activity for Panel 1 with the average activity.
2) Analysis of the effects of random versus non-random emplacement on vertical stacking of waste container activity.
3) Analysis of the volume/variance implications on the DOE bounding analysis.

Data for these analyses were retrieved from the WIPP Waste Information System (WWIS). Data were complete for rooms one, two, three, and seven. Waste was only emplaced in the intake drift portion of rooms four through six because of degrading room condition resulting from the time interval between mining and first receipt of waste.

The exact size of each containment package (7-pack of drums, pipe overpacks, standard waste box, or ten-drum overpack) and the exact spacing between packages is not recorded. Therefore, "real" coordinates were not available. For this analysis, the EEG took the room coordinates as assigned by the WWIS group and transformed them into a master grid encompassing all rooms. It was assumed that grid points have a spacing of seven feet and each grid point represents a vertical stack of three containers.

Emplaced Activity in Panel 1

Non-random emplacement of waste results from the campaigning of specific waste streams to the WIPP depending on DOE's agreements with the various states which host the TRU waste and the readiness of particular waste streams for shipment [7]. Table I compares important emplaced radionuclides to date with the average concentration assumed for the repository [8]. With the final emplacement of waste in Panel 1, the degree of deviation between actual emplaced waste and an assumption of random emplacement is apparent. ^{239}Pu is 3.20 times, ^{240}Pu is 2.67 times, and ^{241}Am is 4.13 times the projected repository average for the space occupied by waste. These averages are based on a total volume of waste of 10,496 m^3.

Table I Comparison of emplaced Panel 1 Ci with compliance certification application projections.

Radionuclide	Curies (Ci)	Ci/m^3	CCA* Ci/m^3	Actual/CCA
^{239}Pu	152,000	14.48	4.52	3.20
^{240}Pu	34,290	3.27	1.22	2.67
^{241}Am	120,200	11.45	2.77	4.13
^{238}Pu	6,186	0.59	11.02	0.05
^{241}Pu**	482,024	45.92		

Table IV-VI, CCA (DOE 1996)
Not a tracked radionuclide but important because of its daughter product, ^{241}Am

Analysis of Effects on Vertical Stacking

For each container at each grid location, the total number of Plutonium-239 equivalent Curies (PE-Ci) was computed according the formula and weighting factors [9]:

$$PE-Ci=\frac{^{233}U}{3.9}+\frac{^{237}Np}{1.0}+\frac{^{236}Pu}{3.2}+\frac{^{238}Pu}{1.1}+\frac{^{239}Pu}{1.0}+\frac{^{240}Pu}{1.0}+\frac{^{241}Pu}{51.0}+\frac{^{242}Pu}{1.1}+\frac{^{241}Am}{1.0}+\frac{^{243}Am}{1.0}+\frac{^{242}Cm}{30.0}+\frac{^{244}Cm}{1.9}+\frac{^{252}Cf}{3.9}.$$

PE-Ci were used in this analysis, eliminating the need to analyze multiple radionuclides. However, for performance assessment calculations it is necessary to use individual radionuclide data.

Using the internal volume of each waste container, the total volume of waste was computed at each grid point. The total concentration (PE-Ci/m^3) was then calculated for each stack of three containers.

To compare the actual emplaced waste with what could have been emplaced if done randomly, the following methodology was employed:

1) The concentration (PE-Ci/m^3) at each grid point for each layer (top, middle, and bottom) was calculated.
2) Using a random number generator, the order of each grid location was randomized by layer.
3) The combined concentration was then recalculated for each stack of three containers.

Emplaced waste and randomized waste distributions are shown in Fig. 1. The means of the two distributions are essentially the same, but the distribution of actual emplaced waste is bi-modal with a higher standard deviation and a long high-concentration tail. This results from the physical process of non-random shipment and emplacement. High-concentration containers have a higher likelihood of being stacked together, as will low-concentration containers.

As seen from comparing the top and middle distributions in Fig. 1, the distribution of emplaced stacks of waste containers is similar to the distribution of individual containers. Randomizing the spatial location prior to stacking results in a distribution of stacks that is closer to a normal distribution, or a state of maximum entropy as would be predicted from classical statistical theory (Fig. 1, bottom).

The change of shape from the distribution of individual containers to the stacks of randomized containers results from a change in volume, or statistical support. This volume change causes a change in variation that is affected by the spatial correlation of the containers. The similarity between the distribution of individual containers and that of stacks of actual emplaced waste, i.e. permanence of distribution [10], and their deviation from the randomized distribution, illustrates the degree of non-random emplacement practiced in Panel 1. As the data are randomized and become spatially uncorrelated, classical statistics (based on independence of samples) would predict the empirical results demonstrated by the distribution of randomized stacks. That is, the distribution of emplaced waste would become more symmetrical.

The degree to which the distribution deviates from a randomized case is dependent on the actual data, but the implications of non-random emplacement for intrusion can be shown by comparison of actual and randomized Panel 1 distributions in a probability plot (Fig. 2). It shows the probability of intersecting high-concentration stacks is significantly higher in the non-random distribution versus the randomized distribution. For example, computing the projected average concentration of the Rocky Flats residues from the initial certification inventory information and assuming 20,100 drum equivalents of volume results in a concentration of 84.2 PE-Ci/m^3. From Fig. 2, the probability of intersecting a stack greater than this average is 2% for the randomized case, but is 9% for actual emplacement.

Chapter 4 of the Compliance Certification Application (CCA) [3] states that, “A sampling of 10,000 futures is large enough that the *relatively low* probability combination of three of the waste streams with higher activity loading occurring in a single drilling event is captured in the CCDFs presented..” (italics added). It goes on to state, “…the CCDF is not impacted by

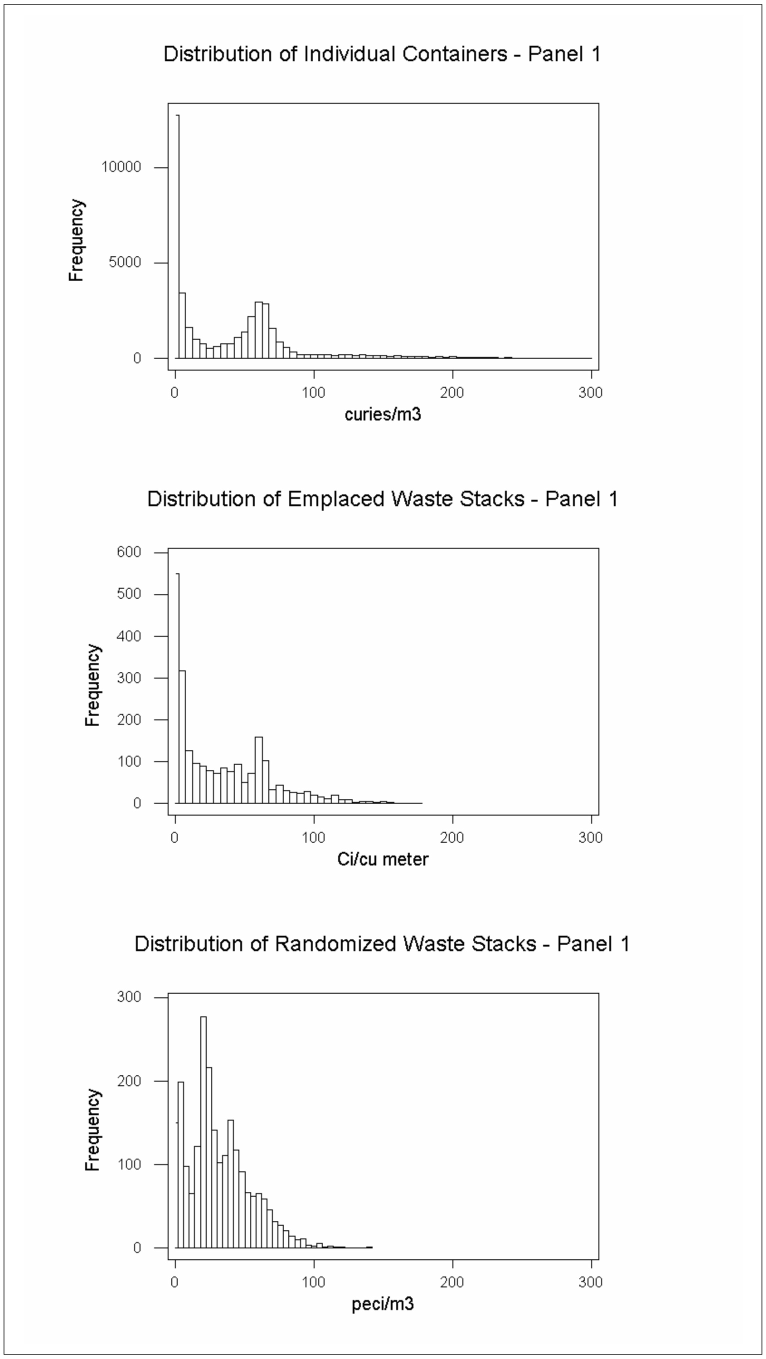

Fig. 1 Distributions of PE-Ci/m^3 in containers, stacks, and randomized stacks for Panel 1.

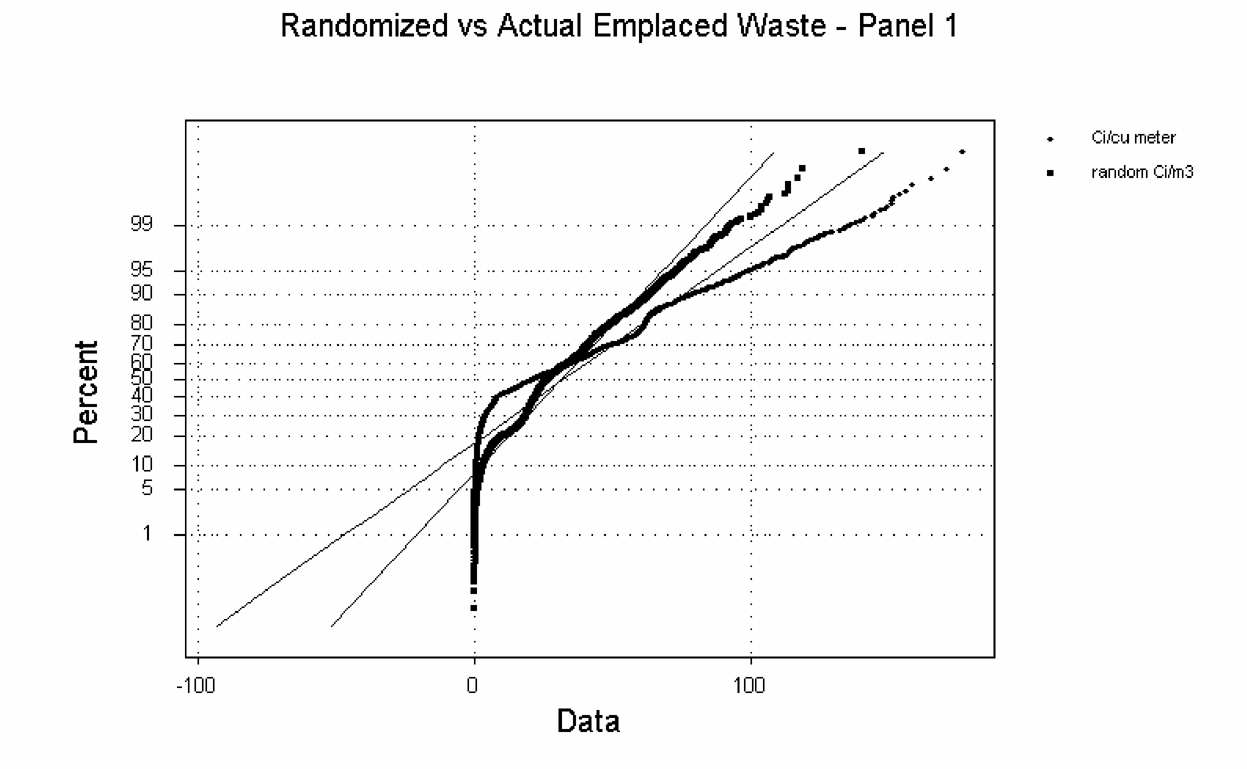
Randomized vs Actual Emplaced Waste - Panel 1

Fig. 2 Distribution of Actual Stacked Waste as Emplaced Compared to the Same Waste as Randomized.

sampling uncertainty so the assumption of random emplacement of containers is not important to the location of the CCDF and a load management plan is not necessary to support performance assessment assumptions". The change in distribution away from randomness caused by non-random emplacement of waste, and the subsequent increase in probability of high concentration intersection during an intrusion, casts doubt on these performance assessment assumptions.

In cuttings and cavings analysis, the sampling of each layer in a stack independently and the use of waste stream averages would appear to result in the calculation of underestimated releases for some realizations, resulting in underestimated uncertainty. Modeling the correlation between waste streams within a stack would reflect operational practice. Sampling waste streams using a distribution of concentrations will not likely change the mean release during performance assessment, but will affect the confidence interval. This is evidenced by the effect that small, high-concentration waste streams have on the confidence limit in previous performance assessments. Using a distribution of values for large volume waste streams instead of the mean concentration will provide a better estimate of the uncertainty associated with cuttings and cavings releases.

Volume/Variance Implications for Spallings Releases

In response to the EEG's concerns about the random emplacement assumption in the CCA [3], the DOE performed a bounding analysis which assumed contiguous emplacement of the Rocky Flats residue waste [11]. This waste stream was selected because it was the highest activity contact-handled waste that had at least 810 drum equivalents volume. The 810 value was one

one-thousandth of the total number of drum equivalents to be emplaced in the WIPP. Therefore, this waste stream would have a probability (conditional on the occurrence of a single intrusion) of intersection of more than 0.001, the probability limit established in 40 CFR § 191.13(a) [12]. However, this probability was based on the assumption of independence of samples and would therefore be a bounding case for random emplacement, not non-random emplacement.

As discussed earlier, about 9 percent of the emplaced three-layer stacks have average concentrations over the estimated Rocky Flats residue average of 84 PE-Ci/m^3. The probability of intersecting high-concentration stacks can be examined for the distribution of a spallings-sized event versus the distribution of an 810 drum-sized unit. The use of the spall-sized volume in an intrusion scenario is similar to the concept of a selective mining unit (smu) in ore reserve estimation [10] or a volume of selective remediation (vsr) in environmental cleanup [13].

The distribution of a spallings-sized event can be approximated by the distribution of stacks. Assuming the volume of three stacked 7-packs of drums, each grid node (or stack) would equal 4.4 m^3. Therefore, the volume of each stack would be close to the 4 m^3 volume in a maximum spallings event. A volume of 810 drums is approximately 40.5 times the volume of a stack of containers (based on an average of 20 drum-equivalents per stack). This could then be represented by a block with dimensions of the square root of 40.5 times the assumed grid size representing a stack, or seven ft. This would result in a block of 44.5 ft. by 44.5 ft. The distribution of these blocks could be calculated from a change of support technique such as Hermite Polynomial Transformation [10].

Hermite Polynomial Transformation requires a variance reduction factor which can be computed after deriving the variance between blocks (810 drum units) and the overall domain. This variance between blocks is computed [14]:

$$\sigma^2(v,V) = \sigma^2(.,V) - \sigma^2(.,v) \qquad \text{(Eq. 1)}$$

where:

$\sigma^2(v,V)$ = variance between blocks of size v within V.
$\sigma^2(.,V)$ = variance of a point within the domain.
$\sigma^2(.,v)$ = variance of a point within a block of size v, (dispersion variance).

The total variance is the computed variance of the individual containers, or 2052 (PE-Ci/m^3)^2. The dispersion variance may be estimated from a variogram model of the samples, or stacked containers [15].

An experimental variogram of the emplaced waste was computed using the GSLIB program GAMV [16]. This variogram was fitted with a spherical model as shown in Fig. 3. The dispersion variance for a point within the 810 drum unit was computed with kriging program subroutines in GSLIB, using this variogram function, and resulted in the variance reduction factor, $\sigma^2(.,v)/\sigma^2(.,V)$, equal to 0.104).

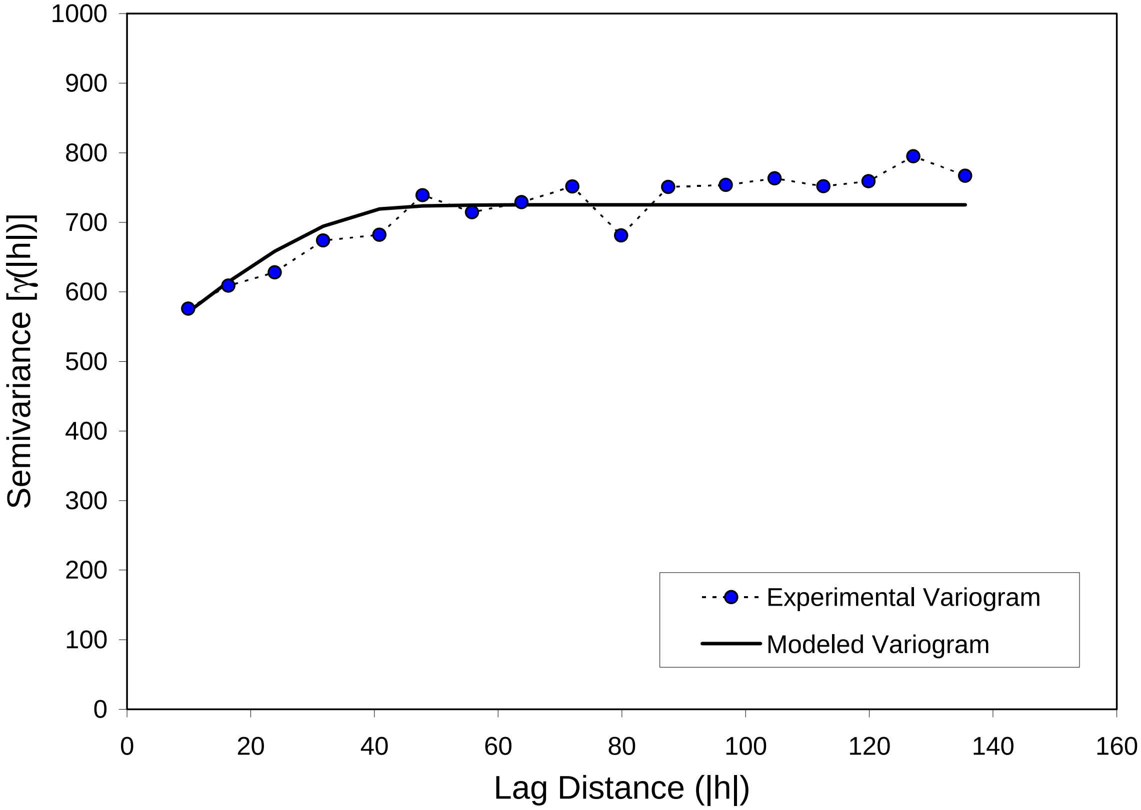

Fig. 3 Experimental variogram of emplaced waste

Using a program for Hermite Polynomial Change of Support [17] a hypothetical distribution of 810 drum units was constructed from the distribution of stacked containers. The probability plots for this distribution, as well as the original distribution of stacked containers (spall units) are shown in Fig. 4. As can be seen, the probability of intersection of a high-concentration stack during an intrusion scenario will be underestimated by assuming volumes of 810 drum units. Therefore, an analysis conditional on a minimum of 810 drums may not represent an adequate bounding case for non-random emplacement of waste.

CONCLUSIONS

Emplacement of waste in the WIPP is dependent on the readiness of particular waste streams for shipment and priorities that may be driven by the DOE's agreements with the various states that host TRU waste. For example, the shipping campaign priority of residues from Rocky Flats has resulted in elevated emplaced activity. For these reasons, non-random emplacement will continue to be practiced at WIPP and performance assessment calculations should reflect this practice.

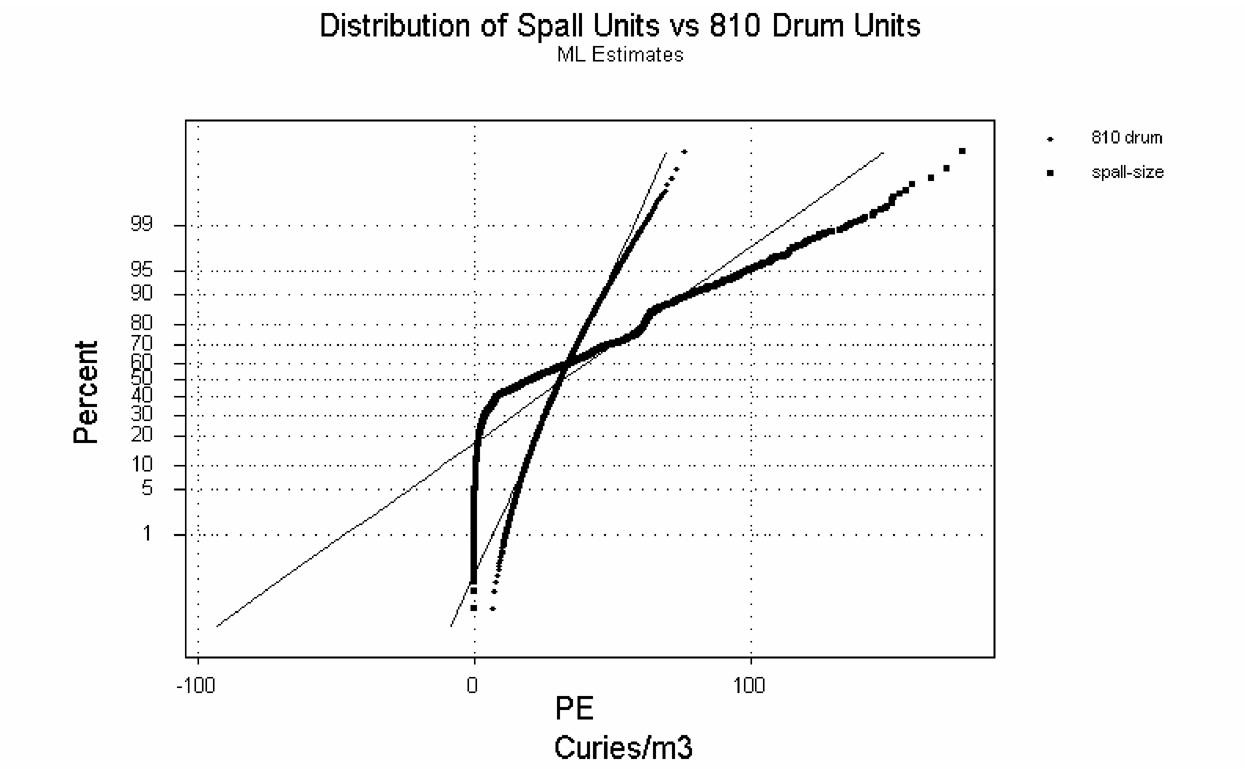

Fig. 4 Distribution of stacked containers (approximate spall units) and the hypothetical distribution of units containing 810 drums.

The distribution of stacks in Panel 1 reflects the distribution of individual containers. This suggests that the performance assessment practice of independently sampling from the full range of waste streams in the inventory does not adequately represent the conditions in the repository. These non-random stacks will have higher high-concentrations and lower low-concentrations than a randomly mixed stack. In addition, the use of waste stream averages will also tend to smooth the distribution of potential releases, especially for large-volume waste streams that may contain a wide-range of PE-Ci/m^3 concentrations. Therefore the uncertainty, as reflected by the 95 percent confidence interval in performance assessment calculations, will be underestimated.

Furthermore, the practice of non-random emplacement may invalidate the premise of the performance assessment bounding analysis for spallings. The DOE bounding analysis for the initial certification assumed independence of samples for selection of the minimum waste stream volume to be analyzed. Independence of samples is not inherent in non-random emplacement, which results in spatial dependence between sample locations. This spatial dependence is evidenced by the structure of the experimental variogram and the "permanence of distribution" observed between the distributions of containers and stacks.

This demonstrated spatial dependence of waste containers then precludes the use of classical statistical techniques which assume spatial independence of samples. Instead, spatial statistical (geostatistical) methods should be used for analysis, performance assessment implementation, and bounding calculations.

RECOMMENDATIONS

The EEG recommends that:

1) The DOE develop intrusion scenarios based upon waste that is already emplaced and anticipated emplacement based on waste shipping schedules. While these schedules will change over time, it is the best information available and presents a more realistic assumption than random emplacement. A spallings event should then be based upon this spatial distribution of waste instead of the mean value of all of the waste.

   Alternatively, the DOE should develop a bounding case based on the distribution of potentially spalled units, recognizing the effects of non-normal distributions which result from the non-random emplacement process. One possibility would be to use geostatistical simulation with different variograms (with a range of spatial correlations) to show the consequences of different emplacement sequences for the future.

2) The DOE should develop and use a methodology for non-random waste emplacement for cuttings and cavings scenarios. This methodology should recognize the likelihood of similar waste streams occurring within a stack of three containers instead of randomly sampling for each layer in the stack. It should also acknowledge the increased probability of high-concentration intercepts, which result from non-random loading instead of using mean values of entire waste streams.

3) The DOE should continue to build a spatial data base of emplaced waste for ongoing analysis and for use during future recertifications.

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