# ASSESSING THE EFFECT OF ACTUAL WASTE EMPLACEMENT PATTERNS ON THE PERFORMANCE ASSESSMENT FOR THE RECERTIFICATION OF THE WASTE ISOLATION PILOT PLANT

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## ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is the only operational deep-geologic repository in the world for transuranic nuclear waste. WIPP opened for disposal activities in March 1999, starting the clock for the periodic recertification required every five years until the repository is closed. The first Compliance Recertification Application (CRA) is due to the U.S Environmental Protection Agency (EPA) by March 2004. The CRA will include an up-to-date performance assessment (PA) that will consider new and changed information since the first certification.

The initial PA, which supported the certification of WIPP, represented waste in the repository as a homogenous composite material. Over the past five years, the U.S. Department of Energy (DOE) has filled one waste panel (Panel 1) and is currently filling another (Panel 2). The waste components of long-term regulatory importance (including quantities of individual radionuclides and other materials in the waste) are inventoried for each emplaced container, and the information is maintained within a comprehensive tracking system known as the WIPP Waste Information System. An examination of the waste emplacement in Panel 1 has led to questions from EPA and other stakeholders about whether the actual emplacement patterns are consistent with assumptions made by the PA for certification.

The actual waste emplaced in Panel 1 includes many pipe overpack containers, which are structurally much stiffer than the standard 55-gallon drums that were assumed for the creep-closure calculations that supported the certification PA. In addition, DOE is seeking permission from EPA to emplace supercompacted waste into the repository, which has different physical and chemical properties than average waste. In support of the CRA, DOE has conducted an analysis of the assumptions regarding waste representation in PA to determine whether these assumptions continue to adequately represent the future state of the repository, given the variety of waste that will be emplaced.

This paper summarizes an analysis designed to assess the importance of waste representation assumptions to PA results. A report by Hansen and others [1] describes this analysis in detail.

## INTRODUCTION

The WIPP is regulated by the EPA according to the containment and individual protection requirements established in 40 CFR Parts 191 and 194. The DOE demonstrates compliance with these requirements by means of performance assessment. Performance assessment estimates probability distributions of releases from any significant processes or events, accounting for uncertainty in the understanding of the processes and in the future of the repository [2]. The conceptual models implemented for the WIPP PA are described in detail elsewhere [3,4].

The DOE initially demonstrated compliance by means of a PA conducted in 1996 for the Compliance Certification Application (CCA), before waste shipments began. This PA assumed that the various waste streams would be randomly distributed throughout the repository. Since 1996, waste emplacement in Panel 1 shows evidence of spatial correlations among the emplaced waste streams, including an abundance of waste packaged in pipe-overpack containers. In addition, the DOE is seeking to emplace waste from the Advanced Mixed Waste Treatment Project (AMWTP) that has substantially different structural and chemical properties than is represented by an average 55-gallon drum. Consequently, DOE conducted analyses to determine whether these heterogeneities in the waste should be represented in the performance assessment.

## HETEROGENIETY OF EMPLACED AND ANTICIPATED WASTE

An examination of the waste emplaced in Panel 1 reveals that the type of waste and associated containers appear to be atypical of future wastes to be disposed of in the remaining 9 panels. Specifically, over half of the waste containers emplaced in Panel 1 are pipe overpacks (POPs), which contain waste from the Rocky Flats Environmental Technology Site (RFETS). POPs are used for wastes with relatively high radioactivity levels in order that the waste can be legally shipped to WIPP. POPs consist of an internal, thick-walled, stainless steel container that is loaded into a standard 55-gallon drum. POPs are considerably stronger than standard drums and therefore may alter the time-dependent creep closure and porosity of rooms. The DOE anticipates that future disposal panels will contain a greater variety of waste streams, because additional sites will be shipping waste. These panels will likely have fewer POPs than seen in Panel 1, because RFETS has almost completed shipment of its high activity waste.

Furthermore, future panels may contain waste with significantly different physical properties than what was considered in the 1996 PA. The AMWTP is being developed to retrieve, characterize, prepare and store Contact-Handled Transuranic (CH-TRU) waste at the Idaho National Engineering and Environmental Laboratory (INEEL) for shipment to the WIPP. The CH-TRU waste at INEEL consists of debris and non-debris wastes. The debris wastes will be processed through a sort, size, and volume reduction (supercompaction) process. The non-debris waste also will be retrieved, characterized, prepared and stored for shipment to WIPP, but will not be supercompacted. The supercompaction process will compact 55-gallon drums of debris waste and place the compacted drums into 100-gallon drums before shipment to the WIPP. The compacted 55-gallon drums will be reduced to a final volume of 15 to 35 gallons, and each 100-gallon container is anticipated to contain from 3 to 5 compacted 55-gallon drums. The final volume of the supercompacted waste is anticipated to be 19,875 $m^3$ or 11.8% of the total allowed waste volume for WIPP (168,500 $m^3$).

The chemical and physical properties of this compacted waste are different from the more typical WIPP waste in several ways. First, the debris waste from INEEL has a relatively large mass of biodegradable materials and after supercompaction this waste will have a significantly higher biodegradable density than the other waste streams coming to WIPP. Higher biodegradable density may lead to greater amounts of gas being produced locally near this waste. Second, even after compaction the debris waste has a significantly lower radioactivity level than the average level in all the WIPP waste. Third, supercompacted waste has a low initial porosity and is very stiff structurally compared to uncompacted waste; in rooms partially filled with supercompacted waste, creep closure and room porosity may be substantially different than in rooms filled with uncompacted waste.

## WASTE PROPERTIES IN PERFORMANCE ASSESSMENT

Within PA, waste has been represented in process models in a variety of ways depending on the particular process. Waste is assumed to be homogeneous for long-term processes affecting the entire repository such as gas generation, brine and gas flow, creep closure, and radionuclide solubility. In these models the chemical properties (e.g., concentration of cellulose) of the waste are defined by the average composition of the entire inventory, and the physical properties (e.g., permeability) are largely based on surrogate waste materials. Releases of brine to the accessible environment assume concentrations based on the repository-scale average radioactivity of all waste streams. For the direct release of solid waste to the surface as a result of drilling, the radioactivity of releases is determined from the average concentration in a few randomly selected waste streams. Waste streams for solids releases are sampled independently with the probability of selecting a waste stream equal to the fraction of repository volume occupied by the waste stream, implementing the assumption that waste streams are distributed throughout the repository in a random fashion.

As waste emplacement proceeds at the WIPP, it is becoming clear that current and future waste to be emplaced will contain heterogeneous waste forms and container types. EPA and stakeholders have raised this issue in recent forums and have asked the question: Are these diverse waste forms and containers adequately represented in the performance assessment calculations? DOE has undertaken a study to answer this question. It is incumbent upon DOE to demonstrate that the representation of waste within the PA remains adequate, given new and different waste packaging. In the following sections of this paper, the setup and results of this analysis are presented.

## ANALYSIS APPROACH

The goal of this analysis was to set up and run an alternative performance assessment calculation that explicitly represented the effect of POPs and AMWTP waste forms. The alternative PA, hereafter referred to as the AMW PA, was conducted in the following order. First, a reexamination of the existing features, events, and processes (FEPs) was performed. This activity identified models, parameters or numerical implementation of models that may be affected by explicit inclusion of supercompacted and pipe overpack wastes in the AMW PA. Second, the identified models, parameters, or numerical implementation of models were analyzed in detail to determine whether changes were required and what those changes would entail. Third, the AMW PA analysis, which implemented the aforementioned changes, was run for one complete replicate (Latin Hypercube sample) and the results were compared to a baseline PA that was run without changes to waste representation. Both PAs used the same waste inventory and the same random sampling for parameters and future events. Finally a sensitivity analysis was conducted to determine the significance to performance assessment results of these waste packages and of waste heterogeneity.

## Review of the Features, Events, and Processes

In the first step of the AMW PA analysis, the FEPs baseline was examined to determine whether the FEPs included in the PA (i.e., screened in) would account for the POPs, and AMWTP waste. The assessment concluded that the FEPs screened in were adequate to represent these waste forms, and that none of the FEPs that had been screened out should be implemented in the AMW PA. Thus, no new FEPs were added to the AMW PA to accommodate the POPs and the AMWTP waste in the inventory. The FEPs analysis concluded that the following models, parameters or numerical implementation of models may be affected by the inclusion of supercompacted and pipe overpack wastes, and merited further investigation:

- Creep closure of waste-filled regions.
- Chemical conditions in the repository assumed for calculation of actinide solubilities.
- Gas generation models.
- Parameters representing hydrological and mechanical properties of the waste (permeability, shear strength and tensile strength).
- Waste heterogeneity in direct release models.
- Mechanisms used in the model for spallings (blowout, stuck pipe and gas erosion.)

Each of these topics are discussed separately below.

## Creep Closure and Waste Porosity

Conceptually, the process of salt creep, brine flow, gas generation, and room closure are coupled in the performance assessment. The computational model for creep closure is implemented in the code used to model brine and gas flow within and around the repository (BRAGFLO) by means of the porosity surface. The porosity surface is essentially a look-up table that gives the value of room porosity for a set of three independent variables: pressure, time and gas generation rate. The porosity surface is derived from a set of detailed structural calculations using a large-deformation finite element code that simulates the closure of a disposal room filled with waste over time for a number of discrete gas generation rates. These detailed results are converted to a porosity surface that represents the porosity of a room filled with a particular type of waste over time. The structural analyses can be repeated for wastes with different properties and multiple porosity surfaces can be defined and applied to different regions of the repository in the BRAGFLO model. In the baseline PA, a single porosity surface is used. However, because the future placement of waste is uncertain, DOE chose to treat the porosity surface for the waste materials as uncertain in the AMW PA by sampling from a set of porosity surfaces defined from four waste types and configurations. These porosity surfaces are not meant to be representative of future waste configurations, rather they are end-member representations which were chosen to exaggerate any effects on room closure and therefore define the range of uncertainty for this process. This treatment of uncertainty reflects the subjective uncertainty of the spatial arrangement of the waste packages, as well as the subjective uncertainty in the response models for the waste packages. To aid in determining the effects of this uncertainty, the AMW PA used the following set of extreme, end-member porosity surface cases that amplify any effects on PA so that the effects could be identified:

1. **Standard Waste Model**. The standard waste model represents a room filled with a homogeneous mix of waste in 55-gallon drums, identical to the assumptions for the CCA. The standard model represents a bounding case of high initial porosity and structurally compliant waste packages. This is the only model that was used in the baseline PA.
2. **Combined Waste Model**. This model assumes that stiff and structurally compliant wastes are mixed within a room. Supercompacted waste is used for the stiff waste, and standard waste is used for the compliant waste. A mix of 2/3 supercompacted waste and 1/3 standard waste (by volume) was selected for this model.
3. **Supercompacted Waste Model**. This model assumes that all waste is structurally similar to supercompacted waste. This model reflects a bounding case where the initial porosity is low and the waste packages are stiff.
4. **Pipe Overpack Model**. This model assumes all waste is structurally similar to pipe overpacks. This model represents a bounding case where initial porosity is high and the waste packages are stiff.

Figure 1 compares waste-room porosity as a function of time for each of the four models at two gas generation rates (no gas generation and high gas generation). In the absence of gas, the Standard Waste Model results in the highest porosity in the first several hundred years, but quickly compresses and has the lowest porosity thereafter. The stiffer waste models are not as easily compressed and retain much of their initial porosity. In the case of rapid gas generation, all waste models have nearly the same porosity after an initial transient period during which the back pressure produced by the gas cause the rooms to open slightly.

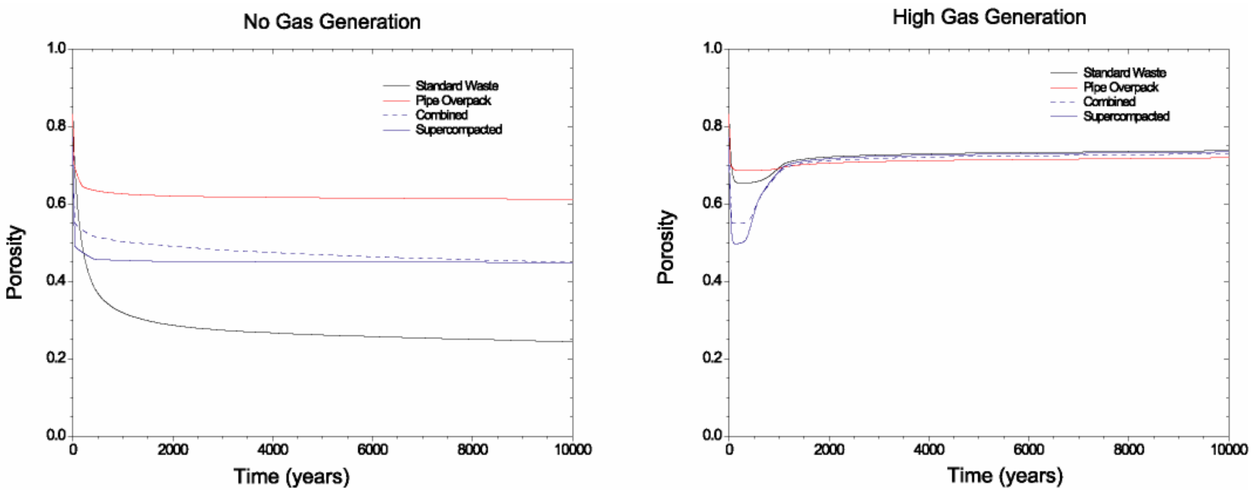

Fig. 1 Waste-room porosity results for the four waste models

In this analysis, the BRAGFLO grid includes two waste material regions, WAS_AREA and REPOSIT, separated by low-permeability panel closures, and having identical hydrologic properties but different porosity surfaces. WAS_AREA represents a single waste panel, which is intruded in disturbed scenarios. REPOSIT represents the nine other panels and is divided into two regions that are separated by a set of panel closures.

Two discrete random variables were sampled to select the porosity surfaces for the WAS_AREA and REPOSIT in each BRAGFLO realization. In the WAS_AREA region one of four porosity surfaces was selected for each realization. The Standard Waste Model, the Combined Waste Model, and the Supercompacted Waste Model were each given a probability of 0.3 of occurring, while the Pipe Overpack Model was given a probability of 0.1. In the REPOSIT region one of two porosity surfaces was selected for each realization. The Standard Waste Model and the Combined Waste Model were each given equal probabilities (0.5) of occurring. The Supercompacted Waste Model and the Pipe Overpack Model were only considered in the WAS_AREA region because these waste configurations are extreme cases and are considered to be very unlikely to occur in more than one panel.

The sampled porosity surfaces in the WAS_AREA and REPOSIT are uncorrelated to allow for all combinations of porosity surfaces in the AMW PA calculations. Certain combinations of waste containers are more or less likely in the inventory than the probability resulting from these distributions. However, there is little basis for assigning probabilities to combinations of porosity surfaces, and the assumption of independence simplifies the sensitivity analysis to determine the significance of the variability in porosity surfaces. Furthermore, the intent of the analysis was not to predict the porosity for future waste emplacement patterns, but rather to cover the range of possible porosity behavior to test whether repository performance is sensitive to this variable.

## Chemical Conditions in the Repository

The chemical conditions in the repository include variables that influence actinide solubility. These include the amount of magnesium oxide (MgO) emplaced in the repository and the concentration of organic ligands present in the waste. MgO is emplaced in the repository as an engineered barrier and is intended to react with any carbon dioxide ($CO_2$) that may be generated by biodegradation processes in the waste. Organic ligands are present in some waste streams and can contribute to the mobilization of actinides and raise solubilities. Both the $CO_2$ generation potential and the concentration of organic ligands may differ considerably in different waste panels if one type of waste is concentrated over the repository average. In the baseline PA, $CO_2$ production potential and organic ligand concentrations were assumed to be homogeneous throughout the repository.

An analysis was conducted to determine whether the homogeneous assumptions related to the chemical conditions in the repository are valid for the AMWTP and POP wastes. This analysis demonstrated that the assumptions underlying the calculation of solubilities for a homogeneous waste model remain valid with the AMWTP and POP wastes included in the inventory. The analysis also shows that if the only nitrate and sulfate available for microbes is that contained in the waste inventory, sufficient MgO will be emplaced to sequester the $CO_2$ in any panel, regardless of the configuration of waste. Neither the AMWTP nor the POP wastes cause factors relevant to calculation of solubilities, such as the fugacity of $CO_2$ ($f_{CO_2}$), the pH, and the concentrations of organic ligands, to deviate significantly from values for a homogeneous waste material. Therefore, no changes were made to the chemical conditions assumed in the repository for the AMW PA calculation.

## Gas Generation

Two gas generation mechanisms are implemented in performance assessment: microbial degradation of organic compounds in the waste and anoxic corrosion of iron-based metals. Microbial activity in the waste is treated as uncertain, occurring with a 0.5 probability. If microbial activity is present, there is a probability of 0.5 that only cellulose materials are degraded; otherwise, microbial activity degrades all cellulosic, plastic, and rubber (CPR) materials. Iron corrosion is assumed to always occur, although the rate of iron corrosion and resulting gas generation is treated as uncertain.

The baseline PA model for waste assumes that both CPR and iron are distributed uniformly throughout the waste-filled regions of the repository. However, any placement of waste in the repository will result in spatially varying concentrations of CPR and iron, due to differences in the content of the various waste streams, which in turn may lead to gas generation that is non-uniform across the repository. The effect of non-uniform gas generation on repository performance is unknown, hence the AMW PA analysis includes spatially varying CPR concentration. Spatially varying iron concentrations were determined to be unimportant as discussed below.

The concentrations of CPR materials in the supercompacted AMWTP waste, in the uncompacted AMWTP waste, and in all other CH-TRU waste streams are substantially different. Table I presents the estimated densities of CPR materials in the waste. These densities were computed by dividing the mass of CPR in the waste streams by the volume occupied by the waste as emplaced in the repository (i.e. container volume). The inventory data indicate that the supercompacted AMWTP waste has densities of CPR materials that are almost a factor of 10 greater than the average densities of these materials in CH-TRU waste from all non-AMWTP waste streams. On the other hand, the uncompacted AMWTP waste streams have densities of CPR materials that are almost a factor of 10 smaller than the average densities of these materials in CH-TRU waste from all non-AMWTP waste streams.

Table I Densities of cellulosic, plastic, and rubber materials in emplaced waste

| **Waste Type** | **Density of Cellulose ($kg/m^3$)** | **Density of Plastic ($kg/m^3$)** | **Density of Rubber ($kg/m^3$)** | **Density of Plas. Pckg. ($kg/m^3$)** |
|---|---|---|---|---|
| Supercompacted AMWTP waste | 302.67 | 204.54 | 79.91 | 0.0 |
| Uncompacted AMWTP waste in TDOPs | 2.68 | 3.55 | 0.01 | 19.11 |
| Uncompacted AMWTP waste in SWBs | 2.73 | 3.56 | 0.01 | 16 |
| All non-AMWTP CH-TRU waste streams | 33.65 | 26.49 | 7.12 | 17.93 |

For this reason, loading a single panel with supercompacted waste could lead to a greater amount of gas being produced in the panel from microbial action, and may affect releases. To determine how non-uniform loading of CPR within the repository might affect performance, an uncertain parameter was defined as the fraction of a single panel's volume that is filled with AMWTP waste (supercompacted and non-compacted). This parameter was given a uniform distribution between 0.2 and 1.0. This range encompasses all the possible distributions from randomly distributed to only AMWTP waste in a single panel. This parameter was used to determine an initial CPR concentration for the representative waste panel (WAS_AREA) and for the rest of repository (REPOSIT), with the total mass of CPR in the waste being held constant.

The baseline PA assumes that iron is uniformly distributed throughout the repository and corrodes at a sampled rate dependent only on local brine saturation. This assumption is implemented by assuming a uniform and constant surface area of iron materials that is available for corrosion. There are waste streams that contain higher iron concentrations than the repository average, such as waste streams being packaged in pipe overpacks, and perhaps supercompacted AMWTP waste, containing compacted 55-gallon drums. However, due to the nature of this iron (e.g. thick walled POPs, and drums supercompacted to lower porosity), it is reasonable to assume that the available surface area of iron will not significantly vary by location in the repository. Furthermore, since iron corrosion consumes brine, it is a self-limiting process and regions with locally greater iron surface area will tend to consume brine faster and thus cause corrosion to decrease in all parts of the repository as brine saturation is lowered.

Previous performance assessments have shown that in all realizations, at least 25 percent of the steel remains after 10,000 years, and in most realization, a larger fraction remains [5,6]. Hence, gas generation due to iron corrosion is limited by the availability of brine rather than the inventory of iron. For these reasons, there is little justification for considering scenarios where the iron availability is distributed non-uniformly.

## Waste Permeability

Waste permeability is an important parameter in the models for brine and gas flow in the repository, and in the models for spallings and direct brine releases. The baseline PA uses a constant waste permeability defined at the scale of a room or panel, rather than at the scale of an individual waste package. The likely mechanical and physical form of the supercompacted and pipe overpack waste packages over time indicates that the permeability of a room containing these waste forms will be at least as great as that of a room containing standard waste, and may likely be higher. In addition, previous studies of the effects of varying permeability [7] indicate that higher permeability tends to reduce releases of solid material. Therefore, a modeling assumption of a homogeneous medium with a constant permeability ($2.4 \times 10^{-13}$ m$^2$) is conservative with respect to the effects on brine and gas flow, and remains appropriate for this analysis.

## Waste Heterogeneity in Models of Direct Releases

Direct releases occur at the time of a drilling intrusion into the waste, and include cuttings and cavings, spallings, and direct releases of brine. Shear and tensile strength of waste materials are important in the calculation of cavings and spallings releases, respectively. The heterogeneity in waste packages may thus affect direct releases. In addition, direct releases may be affected by the placement patterns of waste with varying radioactivity. The changes to the PA to determine the sensitivity of waste mechanical properties and waste placement are discussed below.

Cuttings are solids removed by the drill bit; cavings are additional solids that may be eroded from the borehole walls by the circulating drill fluids. Cavings are largely dependent on the mechanical shear strength of the waste [4]. Supercompacted and pipe overpack waste packages will be less likely to degrade and corrode over time than standard waste forms, and consequently their mechanical shear strengths may be expected to be equal to or higher than for standard waste. Higher values of shear strength will reduce direct releases by cavings; consequently, this analysis conservatively makes no change to this parameter.

The PA computes releases by cuttings and cavings by combining the volume of material removed from the repository with the radioactivity in the waste. In the baseline PA, each borehole was assumed to intersect a stack of three independently sampled waste streams. The probability of selecting a given waste stream was equal to the waste stream's emplaced volume divided by the total volume for CH-TRU waste. The radioactivity in the released material was determined by averaging the time-dependent radioactivity of the three randomly selected waste streams at the time of intrusion. In effect, the baseline calculation of cuttings and cavings releases accounted for heterogeneity in waste radioactivity but also assumed random placement of the waste.

Randomness in waste placement can be measured by the degree to which the locations of drums from one waste stream are correlated with the locations of drums from other waste streams. Correlations can be considered separately in the horizontal plane and among the vertical stacks of waste. Consistent with 40 CFR 194 Section 33(a)(2), PA assumes that drilling events can occur at any location of the repository with equal probability. Therefore, drilling locations are not conditioned on the locations of previous intrusions. As a result, any horizontal correlations in waste location are of no consequence. However, any vertical correlations among waste streams might influence the results of the cuttings and cavings releases.

The AMW PA also computed cuttings and cavings releases by assuming random placement of the waste both horizontally and vertically. Releases were based on a random sample of three waste streams, representing a completely random vertical arrangement of the waste in the repository. The sensitivity to the assumption of random placement was determined by a second calculation of cuttings and cavings releases based on a random sample of a *single* waste stream, representing a completely correlated vertical arrangement of the waste in the repository. Such a configuration was meant to represent an extreme end-member emplacement pattern and is not likely to be representative of actual waste emplacement. However, this approach tests the sensitivity of releases to spatial correlation of waste emplacement. Comparison of the two release calculations illustrates the importance of the assumption of random waste placement.

Spallings are solid materials blown into the borehole by gas flow through the waste at the time of a drilling intrusion. The spallings process assumes that the waste is a mechanically homogeneous material defined by parameters such as tensile strength and permeability that are constant for each realization. Tensile strength of the waste is a particularly important parameter for spallings releases [7]. As in the discussion of shear strength for cavings releases, the tensile strength of supercompacted and pipe overpack waste packages may be expected to be equal to or higher than for standard waste. Higher values of tensile strength reduce direct releases by spallings; consequently, this analysis makes no change to this parameter.

In the baseline PA, spallings releases were computed by multiplying the volume of material removed by the average radioactivity of the waste in the entire repository at the time of intrusion. Use of the average radioactivity was considered appropriate, because the maximum spall volume was as large as 4 $m^3$, which represents the volume of waste contained in as many as 19 drums. The average radioactivity in 19 randomly selected waste streams approximates the average radioactivity in all waste streams. Thus, the baseline spallings model incorporates the assumption of random placement of waste, albeit on a larger scale than for cuttings and cavings.

The AMW PA continued the practice of computing spallings releases from the average radioactivity across the entire repository. The sensitivity analysis in this report assessed the significance of using a repository-scale average radioactivity rather than the average of the radioactivity of the three waste streams chosen for the cuttings and cavings release calculation. In addition, the spallings releases were recalculated assuming the radioactivity was equal to that used by the cuttings and cavings. Comparison of the two spallings release calculations illustrated the effect on spallings releases of heterogeneity in waste stream radioactivity, and of random emplacement of waste in the repository.

Direct brine releases (DBR) are volumes of contaminated brine that can flow from the waste into a borehole during and immediately after a drilling intrusion. Direct brine releases are computed by first calculating a volume of brine that would flow into the borehole, then multiplying by the activity of radionuclides in the brine, either dissolved or sorbed to colloids. The calculation of DBR volumes assumes that the waste is homogeneous by assuming a constant permeability for all realizations. As explained above, the AMW PA does not deviate from this practice.

The concentration of radionuclides in brine is assumed to be uniform throughout the repository, reflecting an assumption that brine within the waste is well-mixed. This assumption is not challenged by the presence or properties of the supercompacted or pipe overpack wastes. Therefore, the AMW PA does not make changes to the DBR calculations.

### Summary of Model and Parameter Changes

In summary, this section presents analyses of the possible changes to waste representation in process models to account for the mechanical and hydrologic properties of supercompacted and POP wastes, and to represent heterogeneity in the waste materials. Table II summarizes the results of the analyses.

Table II Representation of supercompacted waste, POP waste, and waste heterogeneity.

| **Model or Parameter** | **Variation from Baseline PA (if any)** |
|---|---|
| Waste Porosity | **Varied**: Implemented uncertain parameters for selecting porosity surfaces for waste-filled regions that represent bounding porosity cases. |
| Radionuclide Solubility | Same as baseline; chemistry of new waste is consistent with current baseline calculation of solubilities. |
| Anoxic Corrosion | Same as baseline; chemistry of new waste is consistent with baseline corrosion models. |
| Gas Generation Models | **Varied**: Implemented uncertain parameter representing non-uniform CPR concentration in waste-filled regions. |
| Waste Permeability | Same as baseline; new waste forms likely have higher permeability on a room scale than the standard waste forms. |
| Cuttings and Cavings | No change; current range of shear strength is extremely conservative for all waste forms. Sensitivity analysis examines the significance of random placement assumption. |
| Spallings | No change; sensitivity analysis examines the significance of assumption of random placement. |
| Direct Brine Release | No change; assumption of well-mixed brine is still valid. |

## RESULTS OF PERFORMANCE ASSESSMENT

This section presents the results of the AMW PA and discusses the effects of heterogeneous waste representation on repository performance. Final PA results are presented as complementary, cumulative distribution functions (CCDFs), which specify the probability of exceeding various levels of cumulative release over the 10,000-year regulatory period. CCDFs are the primary measure of compliance with the containment requirements of 40 CFR 191.13. In order to understand these results, it is sometimes necessary to discuss intermediate results of the individual process models. The results of the AMW calculation are compared to a separate calculation, in which the waste is represented as in the baseline PA without the changes noted in Table II. Except for the new sampled parameters introduced for the AMW calculation, these two calculations share the same sampled parameter values for each realization and thus individual realizations can be compared.

The intermediate results of repository pressure, brine saturation, waste-room porosity and brine flow up the borehole as a function of time provide inputs to the direct release models of spallings and direct brine release. Figure 2 compares plots of these variables for all realizations as a function of time for the two calculations. The results are from the disturbed "S2" scenario, which represents a drilling intrusion at 350 years that intersects a pressurized brine reservoir beneath the repository. These results indicate that the most obvious difference between the two calculations is that waste porosities in the AMW realizations tend to be higher and extend over a greater range than in the baseline calculations[i]. The higher porosities seen in the AMW calculations are expected since the total amount of gas generated is similar to what is produced in the baseline calculation and the different porosity surface models relate porosity to pressure and time differently. Pressures rise more rapidly in the AMW calculations than in the baseline runs during the first several hundred years. But after this time the mean, 10th and 90th percentile pressures are all lower in the AMW runs than in the baseline calculations (not shown). This pattern of higher early pressures and lower, long-term pressures is seen in all scenarios modeled. The higher early pressures are caused by lower initial porosity in rooms filled with dense, stiff wastes. The lower, long-term pressures are a result of greater total pore volume within the repository as a result of the generally higher, long-term porosity caused by stiff wastes cribbing up the rooms.

Brine saturation varies for individual vectors between calculations, but the overall saturation range is very consistent between calculations. Brine flow up the borehole is nearly identical between calculations.

To determine how these differences in porosity and pressure affect total releases, mean CCDFs for each release mechanism are compared in Figure 3. The mean CCDFs are very similar between calculations, however spallings releases tend to be less likely to occur and DBR releases tend to be greater in magnitude at low probabilities. Spallings are less likely because of the generally lower pressures. DBR is higher at very low probabilities because of higher pressures in the first several hundred years. These conditions tend to result in larger DBR release volumes at early times, when the radioactive source term is at its highest.

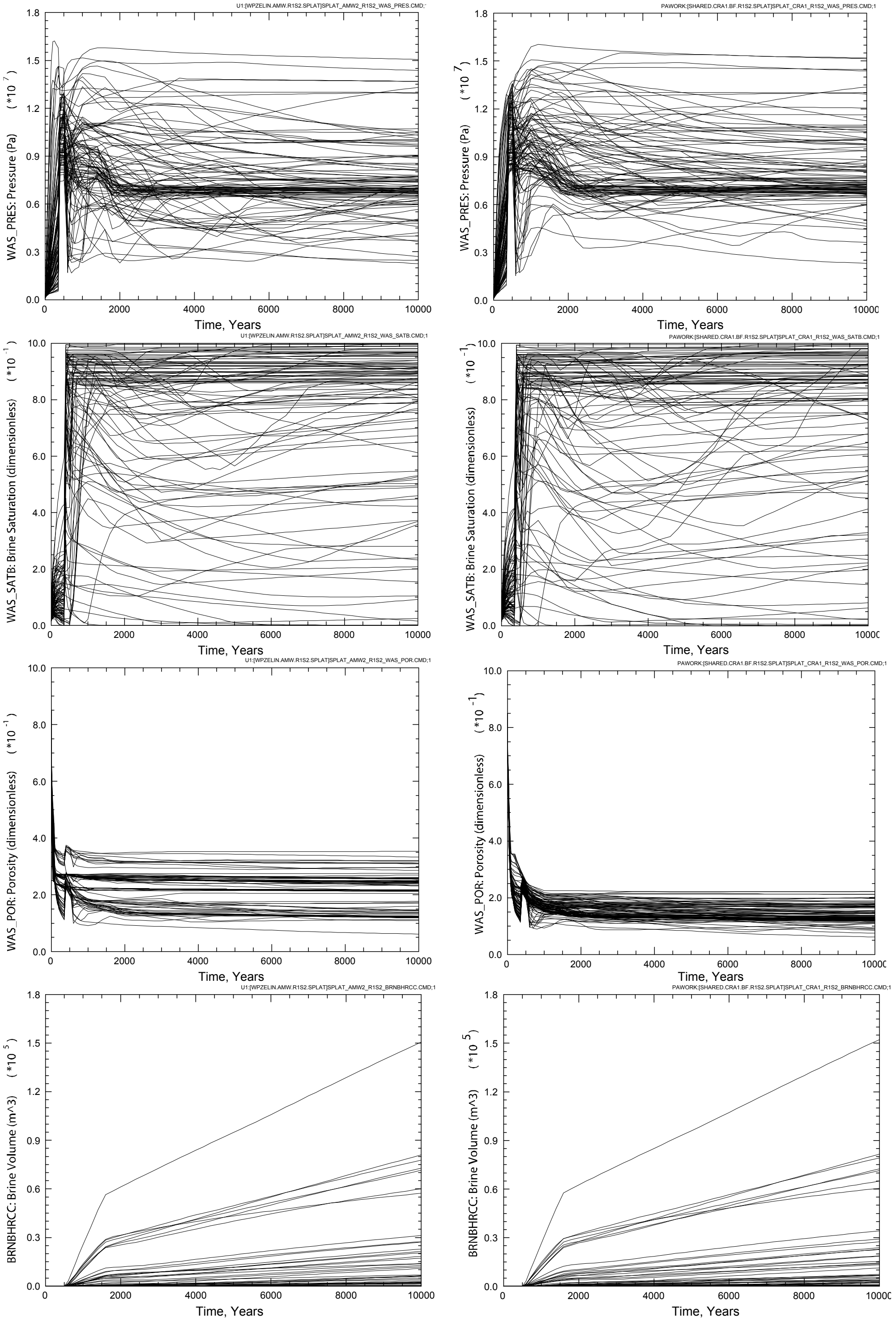

Fig. 2 Plots of Waste Pressure, Brine Saturation, Porosity, and Brine Flow Up the Borehole as a Function of Time for all Realizations of a Disturbed Scenario with a Brine Reservoir Intrusion at 350 Years. Plots on the Left are for the AMW Calculation and Plots on the Right are From the Baseline Calculation.

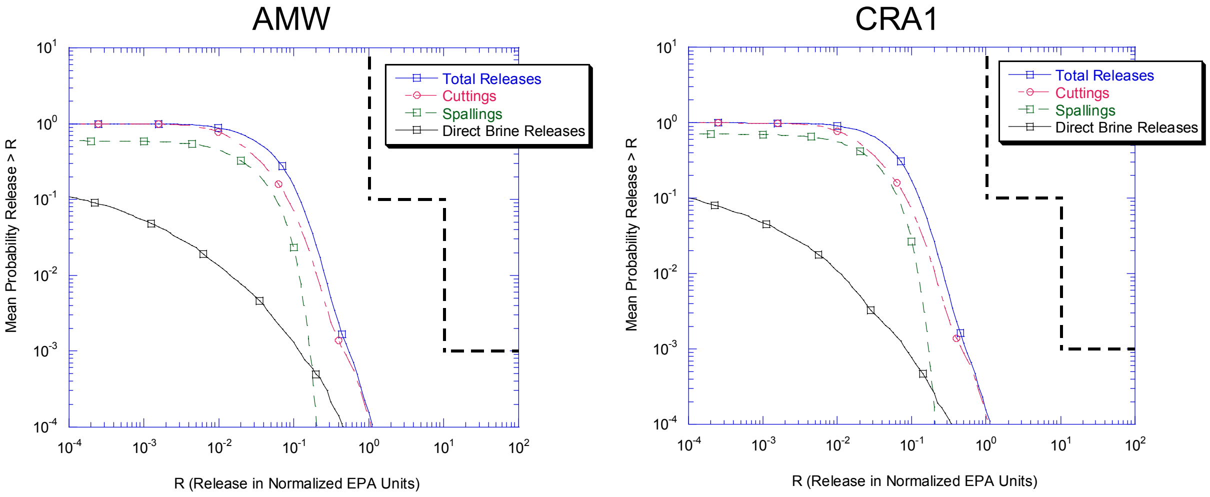

Fig. 3 Compares mean, total and component CCDFs for the AMW and baseline PA calculations.

## Sensitivity Analysis

The essential difference between the AMW and baseline calculations is that three parameters were uncertain in the AMW calculations that were considered constant in the baseline. These parameters included the fraction of a single waste panel filled with AMWTP waste, and two independently sampled porosity surfaces that were applied to the single waste panel and the rest of repository, respectively. A sensitivity analysis was conducted to determine the sensitivity of releases to these three sampled parameters.

The results of the sensitivity analysis concluded that the fraction of a single waste panel filled with AMWTP waste did not have any discernable effect on repository pressures. This is contrary to what might have been expected due the potential to concentrate biodegradable materials within a single panel. Instead, the porosity surface variables turned out to be more important to pressure than the amount of biodegradable material in the single panel. In general, porosity and pressure are inversely proportional. The Pipe Overpack Model resulted in the highest porosities and tended toward lower pressures. However, because the rest of repository represents 90% of the total volume of the repository, the porosity surface applied to this region was the most sensitive input variable to the difference in pressure between the AMW and baseline runs. The greatest difference between AMW and baseline pressures occurred when the Combined Waste Model was applied to the rest of repository. This configuration resulted in higher porosity and lower pressures than in the baseline calculations, which implemented the Standard Waste Model in all areas of the repository. The higher porosity of the Combined Waste Model results in larger total pore volume in the repository, which leads to lower pressures.

## Effect of Heterogeneous Waste Distribution in Direct Releases

As part of the sensitivity analysis, the importance of the assumption of random waste placement in the calculation of direct releases was evaluated. Cuttings and cavings and spallings releases were recalculated assuming that only one waste stream was released per intrusion instead of three waste streams. The assumption of one waste stream represents a bounding case of non-random waste emplacement for PA where waste streams are perfectly correlated in the vertical direction. Figure 4 presents a comparison of the mean and 90th percentile CCDF curves for these cases for both mechanisms. At probabilities above ~0.001 the standard method of choosing three waste streams for cuttings and the repository average radioactivity for spallings resulted in slightly higher releases, although the difference was not that great. Below a probability of ~0.001 choosing one waste stream resulted in higher releases. This increase is due to the low probability of hitting a high activity waste stream. This result indicates that for the probability range important to PA (>0.001), the assumption of randomly emplaced waste in the vertical direction is conservative since it results in greater releases. The spatially correlated bounding case results in greater releases at very low probabilities, but as an end member case it greatly overestimates the actual vertical correlation among the waste that has been and will be emplaced.

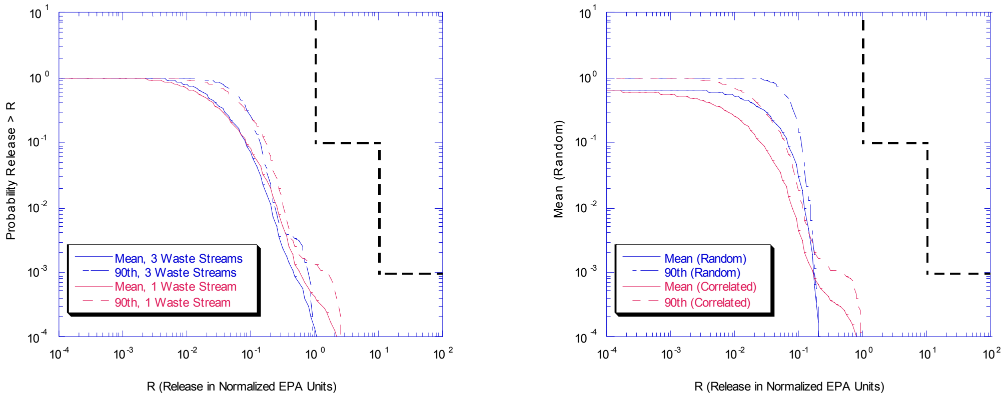

Fig. 4 Sensitivity of Cuttings and Cavings (Left) and Spallings Releases (Right) to Random Placement of Waste. For the Spallings Figure, “Random” Refers to Repository Average Radioactivity and “Correlated” Refers to Radioactivity in the 3 Randomly Sampled Waste Streams Used for Cuttings.

## SUMMARY AND CONCLUSIONS

Performance assessment is the primary tool used by DOE to demonstrate compliance with the long-term disposal regulations in 40 CFR 191 (Subparts B and C) and the compliance criteria in 40 CFR 194. Previous PAs have used the simplifying assumption that the waste would be randomly placed in the repository, and could be represented as a homogeneous material. As new waste containers and waste forms are being emplaced in the WIPP it is necessary that the DOE demonstrate that the assumptions used in PA analyses supporting compliance decisions continue to adequately represent these diverse waste types.

A PA analysis (AMW) has been run in which several important waste characteristics are treated as uncertain. These characteristics include (1) the mechanical response of the waste to creep closure, as implemented by the porosity surface used to represent the waste, and (2) the distribution of biodegradable materials within the repository, which may influence gas generation and pressure in the repository.

Analysis of results from the AMW PA showed that total normalized releases from the repository fall below the regulatory limits specified in 40 CFR 194, thus demonstrating compliance with the regulations regardless of how waste is represented in the calculations. Comparison of the results of the AMW PA and baseline PA shows essentially the same range of uncertainty in repository performance. Thus, the explicit representation of supercompacted waste and waste in POPs in PA does not result in significant changes to the range of estimated repository performance.

In addition, a sensitivity analysis showed that repository pressure and total releases were quite insensitive to the uncertainty in CPR distribution. The sensitivity analysis showed that, among the four porosity surfaces considered, the application of the Pipe Overpack Model resulted in the highest porosity, but that the Combined Waste Model in the rest of repository had the greatest effect on repository pressures. Pressures were systematically lower in the AMW calculations than in the baseline PA and porosity was typically higher. However, AMW mean total releases were not significantly different than for the baseline PA. Thus, the sensitivity analysis concludes that CPR materials can continue to be represented as homogeneously distributed, and that PA should continue to use the Standard Waste Model to represent waste porosity.

Finally, the sensitivity analysis considered the importance of the assumption of random waste placement and spatial correlation among waste streams in the calculation of direct releases. The analysis found that the mean and 90th percentile CCDFs for cuttings, cavings and spallings releases are not significantly different when waste is placed randomly or when waste is placed as contiguous blocks comprising single waste streams. Furthermore, above a probability of 0.001, the practice of selecting three waste streams for cuttings and the repository average radioactivity for spallings results in greater releases and is thus conservative. Thus, this analysis concludes that direct releases are relatively insensitive to uncertainty in the spatial arrangement of the waste and the current practice of assuming no spatial correlation of waste streams in vertical stacks is conservative.

This analysis concludes that repository performance with AMWTP wastes included in the inventory complies with the regulations specified in 40 CFR 194. Moreover, explicit representation of the specific features of supercompacted waste, such as structural rigidity and high CPR concentration, is not warranted, since the PA results are insensitive to the effects of these specific features. Finally, this analysis concludes that PA results are not significantly affected by the assumption of random waste placement and the representation of waste as a homogeneous material.

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[i] Note that the porosity values shown in figure 2 are lower than shown in figure 1. This is because the porosity values used in the flow calculations (figure 2) are an equivalent porosity assuming an unchanging room volume while the porosity values from the geomechanical calculations (figure 1) represent true, predicted room porosity.