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Assessment Of Impacts On Long-Term Performance From Supercompacted Wastes Produced By The Advanced Mixed Waste Treatment Project

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EXECUTIVE SUMMARY

The Idaho National Engineering and Environmental Laboratory (INEEL) has developed the Advanced Mixed Waste Treatment Project (AMWTP) to process 55-gallon drums of CH TRU debris waste prior to shipment to the Waste Isolation Pilot Plant (WIPP). Processing at the AMWTP will involve retrieval, characterization, repackaging, and compacting 55-gallon drums of debris waste and placing the compacted drums into 100-gallon drums prior to shipment. Emplacement of supercompacted waste in the WIPP was not considered in the inventories for the Performance Assessment Verification Test (PAVT) (DOE 1997a; DOE 1997b) and is not explicitly represented in current predictions of long-term repository performance.

This report provides an assessment of the possible long-term performance impacts from emplacement of supercompacted AMWTP waste at the WIPP. This impact assessment is based on consideration of the physical state of AMWTP waste, the expected number of shipments of supercompacted waste, and the inventory and results from the PAVT, which is the current baseline for performance assessment (PA). An evaluation of the AMWTP is appropriate because the projected volume of uncompacted AMWTP waste is more than twice the volume of INEEL waste in the PAVT inventory.

Since the PA methodology uses features, events and processes (FEPs) as a starting point to develop scenarios and identify conceptual models, it is logical that assessment of potential changes to PA begin with an evaluation of impacts to the current FEP baseline. An analysis of the potential impacts of AMWTP waste on the FEP baseline has been performed by Sandia National Laboratories (SNL 2002a). This analysis identifies FEPs related to AMWTP waste that can potentially affect parameters, models, or codes within the PA baseline, but does not quantify their impacts.

The purpose of this report is to quantify the inventory changes from AMWTP waste and evaluate their potential impacts on long-term repository performance. This evaluation assumes that the increased volumes projected for the AMWTP are added to the PAVT inventory, even though this would require future approval of an increase in the maximum limit for cellulosics, plastics, and rubbers, as discussed below. The results of this evaluation are as follows:

- The mass of iron-based materials increases by 11% in a repository with AMWTP waste in comparison to the PAVT. The increased mass of iron will have little impact on gas pressure because there is already an excess of iron-based materials in the repository.

- The mass of cellulosics, plastics and rubbers (CPR) in the repository with AMWTP waste could increase by 18% in comparison to the PAVT. This increase brings the projected mass of CPR at repository closure to 2.46×10^7 kg, a value that is greater than the maximum limit of 2×10^7 kg for CPR (DOE 1996a, Table 4-10). The emplaced mass of CPR is tracked in the WIPP Waste Information System and will not reach the existing limit for many years. The limit cannot be exceeded without prior approval from the U.S. Environmental Protection Agency (EPA), per the requirements of 40 CFR §194.24(e), and the DOE is not currently requesting such a change. If emplaced, the increased mass of CPR could increase gas pressure in some realizations, but should have little impact on normalized release.

- Supercompaction of debris waste will have little impact on the parameter values and distributions for final waste density; waste shear strength, and waste permeability, and on the porosity surface because the range of final compacted waste volumes from the AMWTP and from the *in situ* room closure process are similar.

- The repository will still maintain a reducing environment because the mass of iron increases slightly relative to the mass of waste.

- The compliance margin for magnesium oxide (MgO) will remain at 1.67, the current baseline value, unless the EPA approves a future request to increase the maximum limit of 2×10^7 kg of CPR in the repository. If the maximum limit on CPR is raised to 2.46×10^7 kg, the compliance margin for MgO would be reduced from 1.67 to 1.42. Sufficient MgO would still be available to sequester all carbon dioxide generated by microbial degradation, even with the very conservative assumptions in the current baseline.

- AMWTP waste will have little impact on colloidal suspensions because the additional iron in AMWTP containers will help to maintain a similar chemical environment to that for the PAVT. Under these conditions, the concentration of colloids and their ability to transport radionuclides are unchanged.

This impact assessment also considered the six waste characteristics that have a significant effect on disposal system performance (EPA 1998, page 27389). Appendix WCA, Waste Characterization Analysis, of the Compliance Certification Application (CCA)(DOE 1996a) identifies waste characteristics and components that can influence the containment of waste and that are included as inputs to the computer models and codes used in performance assessment. The six characteristics and the potential changes due to supercompaction are identified in Table ES-1.

Table ES-1. Summary of Impact Assessment for the Six Waste Characteristics Important to Long-Term Performance

Waste Characteristic	Impact of the Supercompaction Process on Long-Term Performance
Solubility	No impact on solubility because: 1. A reducing environment will be maintained, and 2. There is enough MgO to maintain the current compliance margin of 1.67 with the maximum limit of 2×10^7 kg for CPR. If the maximum limit on CPR is increased (subject to future approval by EPA) to the projected mass of CPR with AMWTP waste, 2.46×10^7 kg, the compliance margin for MgO would be reduced from 1.67 to 1.42. The quantity of MgO is still sufficient to sequester carbon dioxide generated by biodegradation.
Formation of colloidal suspensions	The presence of a reducing environment in the repository and the presence of sufficient MgO to buffer the pH of brine

Waste Characteristic	Impact of the Supercompaction Process on Long-Term Performance
	solutions will maintain a similar chemical environment to that assumed for the PAVT. The survivability of colloids and their ability to transport radionuclides is unchanged.
Gas generation	The additional mass of iron introduced into the repository will have a minor impact on gas generation because most realizations for the PAVT already have excess iron in the inventory. The additional mass of CPR present in the repository will have no adverse impacts on normalized releases from the repository because normalized release is insensitive to the changes in gas pressure due to AMWTP waste.
Shear strength of waste	The distribution for the shear strength of the waste will remain essentially unchanged because the compacted end state from *in situ* room closure and from supercompaction are in a similar range.
Radioactivity of specific isotopes	The total curies from INEEL decrease by 5% between the inventory for the PAVT and for the AMWTP. This minor change will be accounted for in inventory updates for future performance assessments. The 5% change in activity will have negligible impact on long-term performance.
TRU activity at disposal	The waste unit normalization factor will increase by 18% between the INEEL inventory for the PAVT and for the AMWTP. This increase will decrease the normalized releases from the repository by a few percent.

The potential impacts from AMWTP waste on normalized release are also considered. The complementary cumulative distribution function (CCDF) for cuttings/cavings will not be significantly different for the PAVT and for the repository with AMWTP waste. The mean release for cuttings/cavings will be unchanged because the normalized releases for random or nonrandom loading will not change and because the shear strength of the waste is unchanged. The CCDF for spallings will not be significantly different because final waste density is unchanged, because very few realizations will see an increase in pressure across the 8 MPa threshold for spallings, and because the spallings volume is independent of pressure above the 8 MPa pressure necessary to initiate a spall. Finally, groundwater-mediated releases through direct brine release or through hydrologic connection with the Culebra will not be significantly different because waste and borehole permeabilities are unchanged, because repository pressure will be similar to the PAVT, and because the presence of a chemically reducing environment and the mass of magnesium oxide in the repository are sufficient to maintain actinide solubilities within the same range of values as for the PAVT.

The conclusion from consideration of the six waste characteristics that are important for long-term performance and the potential impacts on normalized release is that there will be no adverse impacts on long-term performance from emplacement of supercompacted wastes in the repository.

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ACRONYMS

AMWTP	Advanced Mixed Waste Treatment Project
CCA	Compliance Certification Application
CCDF	Complementary Cumulative Distribution Function
CH TRU	Contact Handled Transuranic
CPR	Cellulosics/Plastics/Rubbers
CRA	Compliance Recertification Application
DBR	Direct Brine Release
EPA	U.S. Environmental Protection Agency
FEP	Feature, Event and Process
FGE	Fissile Gram Equivalent
FY	Fiscal Year
INEEL	Idaho National Engineering and Environmental Laboratory
LANL	Los Alamos National Laboratory
MgO	Magnesium Oxide
NRC	U.S. Nuclear Regulatory Commission
PA	Performance Assessment
PAVT	Performance Assessment Verification Test
Pu	Plutonium
RH TRU	Remote Handled Transuranic
SRS	Savannah River Site
TRAMPAC	TRUPACT-II Authorized Methods for Payload Control
TRU	Transuranic
TRUPACT-II	TRU Package Transporter, Model II
WCA	Waste Characterization Analysis
WCL	Waste Component Limits
WIPP	Waste Isolation Pilot Plant

1.0 TREATMENT, SHIPMENT, AND EMPLACEMENT OF AMWTP WASTE

The AMWTP is designed to retrieve, characterize, and prepare 65,000 m^3 of contact-handled transuranic (CH TRU) waste at the Idaho National Engineering and Environmental Laboratory (INEEL) for shipment to the WIPP. The CH TRU wastes at INEEL consist of non-debris waste and debris waste. The non-debris waste constitute approximately 30% of the total volume and will not be supercompacted. The debris waste constitute about 70% of the total volume and will be processed through a sort, size, and volume reduction (supercompaction) process. By way of comparison, the volume of CH TRU waste from INEEL for the PAVT is 28,607 m^3. The increased volume of AMWTP waste results from elimination of a separation process that was assumed for the PAVT inventory.

The AMWTP 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 are referred to as "pucks" (see Figure 1). The 100-gallon drums are referred to here as 100-gallon containers, or simply containers, to distinguish them from the 55-gallon drums. Each puck has a final volume of 15 gallons to 35 gallons, and each 100-gallon container is anticipated to contain from three to five pucks, with an average of four pucks per container.

Figure 1. Pucks Produced by Supercompaction of 55-gallon Drums of Debris Waste in the AMWTP

The 100-gallon container is made of steel. The outside height of the container (with lid) is 35 inches and its outside diameter is 32 inches (DOE 2000, Figure 2.1-6). The height of a container is very similar to the height of a 55-gallon drum; however, its diameter is larger (32 inches versus 24 inches). The weight of an empty 100-gallon container is estimated to be 95 pounds (43.1 kg) (DOE 2000, Table 2.1-20).

The loading of pucks into the 100-gallon containers will be managed to meet applicable transportation and waste acceptance criteria. The 100-gallon containers will then be loaded into a TRUPACT-II for shipment to the WIPP. Each TRUPACT-II can hold six 100-gallon containers in two layers of three each (see Figure 2). Assuming that a shipment will consist of two TRUPACT-II packages and one HalfPACT package, each shipment of supercompacted waste from INEEL will have five three-packs of 100-gallon containers, or a total of 15 100-gallon containers containing on average 60 pucks.

The uncompacted AMWTP waste in 55-gallon drums will also be loaded into the TRUPACT-II packages. Each TRUPACT-II can hold 14 55-gallon drums in two layers of seven each. Each shipment of uncompacted waste from the AMWTP will have 35 55-gallon drums, again assuming that a shipment has two TRUPACT-II packages and one HalfPACT package.

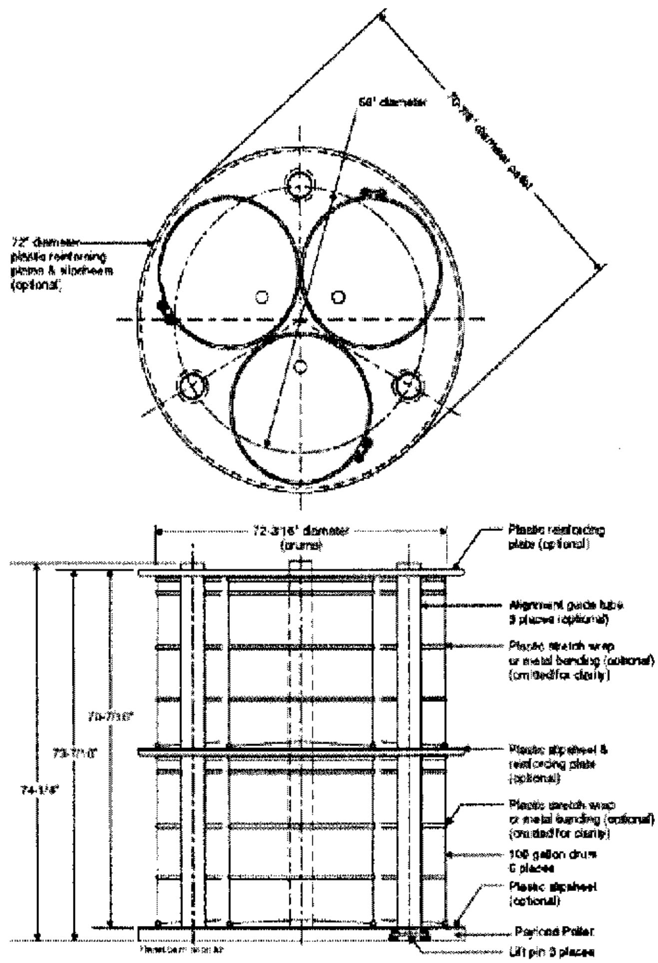

Figure 2. Six 100-Gallon Drum Payload Assembly Configuration (DOE 2000, Figure 2.1-7)

The loading of pucks into containers is subject to applicable transportation requirements and will therefore be restricted by fissile loading limits. The specific limits are as follows:

- Each 100-gallon container or 55-gallon drum is limited to no more than 200 grams of ^{239}Pu fissile gram equivalents (FGEs) by the Waste Acceptance Criteria for the Waste Isolation Pilot Plant (DOE 2002a). In effect, a drum or a container has the same FGE limit, although the FGE limit for a TRUPACT-II is more restrictive.

- Each TRUPACT-II or HalfPACT is limited to no more than 325 grams of ^{239}Pu FGEs by the TRUPACT-II Certificate of Compliance (NRC 2002).

Since a TRUPACT-II can transport six 100-gallon containers with an average of 4 pucks per container, it follows that an average puck has 325/24 = 13.5 grams of FGEs if the container is loaded to the maximum FGE limit. Similarly, a TRUPACT-II can transport 14 uncompacted 55-gallon drums, so the average 55-gallon drum has 325/14 = 23.2 grams of FGEs if the package is loaded to the maximum limit. These average values should be interpreted cautiously because although the FGEs per puck are less than for a 55-gallon drum, the number of pucks is greater so that the maximum total loading for two seven-packs of 55-gallon drums or two three-packs of 100-gallon containers is the same. The fact that the maximum loading is the same for both seven-packs and three-packs is useful for limiting releases due to cuttings/cavings, as discussed in Section 4.1.

The first shipment of uncompacted waste from INEEL is currently planned for March 2003. The first shipment of supercompacted waste is planned for October 2003. The planned number of shipments of CH TRU waste from INEEL for Fiscal Year 2004 (FY'04) through FY'12 is shown in Table 1 (DOE 2002b).

Table 1. Planned Shipments for AMWTP Waste to WIPP

	FY'03	FY'04	FY'05	FY'06	FY'07	FY'08	FY'09	FY'10	FY'11	FY'12	Totals
Uncompacted Waste	333	660	660	660	660	660	165	12	12	11	3,833
Supercompacted Waste	0	240	480	480	480	480	393	324	324	295	3,496

A total of 3,496 shipments of supercompacted AMWTP waste are planned for the FY'04 through FY'12. The WIPP would receive a total of 52,440 100-gallon containers with supercompacted wastes, assuming that each shipment had 15 containers.

The number of uncompacted CH TRU shipments from INEEL is anticipated to be greater than the number of supercompacted shipments. In addition, the Savannah River Site (SRS) and the Hanford and Los Alamos National Laboratory (LANL) sites will be accelerating their shipments of CH TRU wastes beginning in FY'04, as shown in Table 2 (DOE 2002b, Section 5). The U.S. Department of Energy (DOE) has concluded from these shipping plans that there will be a wide variety of waste streams arriving at the repository during any year.

Table 2. Planned Shipments for CH TRU Wastes from SRS, Hanford, and LANL to WIPP

	FY'03	FY'04	FY'05	FY'06	FY'07	FY'08	FY'09	FY'10	FY'11	FY'12	Totals
SRS	144	144	144	144	148	147	147	147	66	4	1235
Hanford	10	80	96	96	99	101	104	107	115	111	919
LANL	81	167	167	167	167	196	196	215	0	0	1356

The operational plan at the repository is to emplace the supercompacted wastes in among the seven-packs of uncompacted 55-gallon drums from all sites. This simple approach is available because a three-pack of 100-gallon containers fits within the footprint of a seven-pack of 55-gallon drums, as illustrated in Figure 3. In addition, the outside height of the 55-gallon drum is very similar to that for a 100-gallon container. It follows that a three-pack and a seven-pack are physically configured as a one-for-one replacement for the purpose of waste handling in the repository.

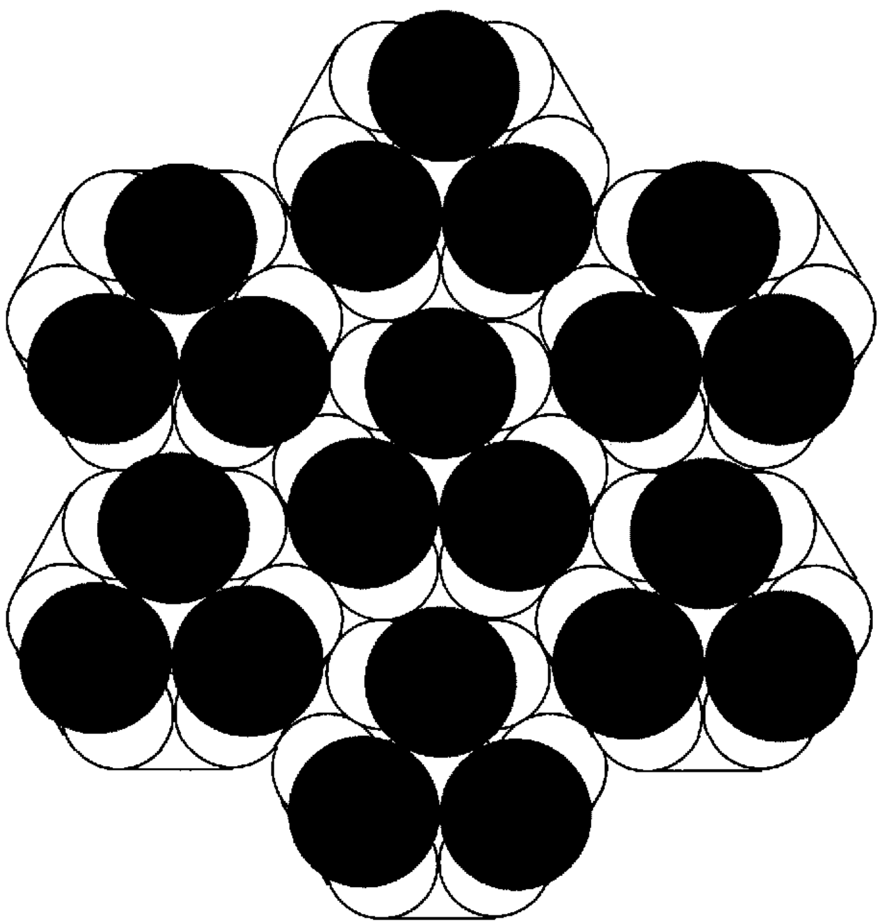

Figure 3. Schematic Diagram Showing That Three-Packs of 100-gallon Containers (Shown as Dark Circles) Fit within the Footprint of Seven-Packs of 55-gallon Drums (Shown in Outline).

2.0 TECHNICAL APPROACH

2.1 FEP Impact Assessment

The performance assessment (PA) methodology uses features, events and processes (FEPs) as a starting point to develop scenarios and to identify conceptual models and their associated input parameters. In the CCA (DOE 1996a), the DOE identified all significant processes and events that may affect the disposal system. Over 1,000 FEPs were originally considered for the WIPP, of which 237 were determined to be relevant. Because FEPs are the starting point for PA, it is logical that assessments of potential changes to the PA baseline begin with an evaluation of impacts that a given change might have on the current FEP baseline. To begin this assessment, the current baseline FEP list is searched for FEPs that are related to the proposed change. Once related FEPs are identified, a second step evaluates if the proposed change may present implementation issues within PA.

An analysis to determine the potential impacts of AMWTP waste on the original FEP baseline has been performed by Sandia National Laboratories (SNL 2002a). A total of 74 FEPs that are related to the presence of supercompacted AMWTP waste were identified during this analysis. Of these, 40 FEPS were screened out from further consideration in PA since none require changes in either their screening arguments or the associated screening decisions. Of the remaining 34 FEPs that were screened into PA, no changes to screening information were determined to be necessary. These results indicate that the current FEP baseline is adequate to account for AMWTP waste.

As a second step in the FEP assessment, the related FEPs are evaluated to determine if the proposed change may present implementation issues within PA. This step qualitatively determines if a proposed change potentially affects parameters, models, or codes within the PA baseline. There is no attempt to quantify the changes associated with AMWTP waste, only that an effect may be present. Table 3 identifies the related FEPs that were identified as having possible implementation issues.

Table 3. Screened In FEPs Requiring Further Investigation (from SNL 2000a, Table 3)

FEP ID	FEP Name	Possible Implementation Issues
W2	Waste Inventory	AMWTP waste may increase the fissile mass in localized areas within the repository
W3	Heterogeneity of waste forms	Loading schemes and disposal schedules may present inconsistencies with random emplacement assumption
W5	Container material inventory	AMWTP waste will increase the corrodible metals content over previous estimates.
W32	Consolidation of waste	Initial waste properties (densities) are different than those previously assumed.
W44	Degradation of organic material	AMWTP waste may possess greater amounts of cellulosic material than previous estimates.
W49	Gases from metal corrosion	Greater amounts of gas may be produced than those previously

FEP ID	FEP Name	Possible Implementation Issues
		assumed.
W51	Chemical effects of corrosion	Current reaction rates may need revision.
W64	Effect of metal corrosion	Greater amounts of metal may require revision of coupled chemical processes.
W84	Cuttings	Intersection of a drill bit with a 100-gallon container may cause cuttings releases to increase.
W85	Cavings	AMWTP waste may change waste properties, thereby changing cavings into boreholes.
W86	Spallings	AMWTP waste may have different shear strength/physical properties than those assumed in the CCA.

2.2 Impact Assessment for Long-Term Performance

This report continues the analysis in the FEP assessment (SNL, 2002a). It quantifies the inventory changes for a repository with AMWTP waste and evaluates the potential impacts from these changes on long-term repository performance. The quantitative impacts are evaluated by considering the following issues, which are directly relevant to the FEPs identified in Table 3:

- The number of drums and containers in the repository with AMWTP waste
- Change in mass of iron in the repository with AMWTP waste
- Change in mass of cellulosics/plastics/rubbers in the repository with AMWTP waste
- Compaction of the waste form and its effects on waste density, waste shear strength, waste permeability, and the porosity surface
- Maintaining a reducing environment for chemical reactions and solubility
- Maintaining sufficient magnesium oxide to react with the carbon dioxide generated by biodegradation
- Concentration and stability of colloidal suspensions
- Impact on cuttings/cavings release, including the impact from FGE limits
- Impact on spallings release
- Impact on direct brine release
- Impact on long-term groundwater release

These issues are also directly relevant to the six waste characteristics that have a significant effect on disposal system performance: solubility, formation of colloidal suspensions containing radionuclides, gas generation, shear strength of waste, radioactivity of specific isotopes, and transuranic activity at disposal. The analysis that defined the six waste characteristics that have a significant effect on disposal system performance is provided in Appendix WCA of the CCA (DOE 1996a).

The quantitative evaluation of potential impacts from AMWTP waste on repository performance is based on the following major assumptions:

- Three-packs of 100-gallon containers will be emplaced randomly throughout the repository. This is a reasonable assumption based on the current shipping schedules from INEEL and from other sites in the DOE complex, as shown in Tables 1 and 2.

- A three-pack of 100-gallon containers is a physical replacement for a seven-pack of 55-gallon drums. This assumption is reasonable because a three-pack and a seven-pack have similar height and footprint for the purpose of waste handling in the repository and because a 55-gallon drum and a 100-gallon container have the same height, weight, and FGE limits. Note that inventories for radionuclides, ferrous materials, and cellulosics/plastics/rubbers may be different, as discussed in Section 3.

- Each 100-gallon container is filled with an average of four pucks of supercompacted waste for the purposes of estimating the mass of iron in the repository.

- The PAVT (DOE 1997a; DOE 1997b) represents the baseline for comparison of impacts from supercompacted wastes. The performance assessment for the PAVT assumes random emplacement of waste streams throughout the repository. The inventory for the PAVT included debris and nondebris wastes from the INEEL, but did not consider supercompaction. The increased volume of uncompacted CH TRU waste from the AMWTP is the result of eliminating a separation process that was assumed for the PAVT inventory.

- CH TRU waste fills the total available volume of 168,500 m^3. For the PAVT, there are (168,500 m^3/0.208 m^3 per drum) = 810,000 drums of CH TRU waste, where 0.208 m^3 is the volume of a 55-gallon drum. For the repository with AMWTP waste, this volume is filled with a combination of 55-gallon drums and 100-gallon containers, based on shipments from the DOE complex.

2.3 Radionuclide Inventory from AMWTP Waste

The inventory of radioisotopes is important for long-term performance. The inventory of 12 major radionuclides in the CH TRU waste streams from INEEL was analyzed for this impact assessment, and the results summarized in Table 4. Data for the debris wastes from the AMWTP are based on the preliminary radionuclide inventory update from INEEL for the Compliance Recertification Application (CRA). These preliminary radionuclide inventory data have not been decayed to a standardized year.

The second column in Table 4 is the INEEL radionuclide inventory for the PAVT, based on Revision 3 of the Transuranic Waste Baseline Inventory Report (DOE 1996b, Appendix C, Site Specific Stored Radionuclide Inventories). The third column in Table 4 is the estimated radionuclide inventory for the non-debris CH TRU wastes from AMWTP. This radionuclide inventory is estimated by scaling the INEEL radionuclide inventory for the PAVT by a factor of 0.648, which is the ratio of the nondebris waste volume (18,539 m^3) to the original volume of INEEL waste for the PAVT (28,607 m^3). The fourth column in Table 4 is the AMWTP inventory for debris wastes. The fifth column is the sum of the nondebris and debris wastes from the AMWTP. Note that the Pu isotopes in the Pu-52 and Pu-83 waste forms are included in the totals for the AMWTP.

Table 4 shows that total curies of CH TRU wastes from INEEL have decreased by about 5% between the PAVT inventory and the AMWTP inventory. The data in Table 4 can also be analyzed for the TRU radionuclides that contribute to the waste unit normalization factor. These radionuclides are shown in italics. The TRU curies for the waste unit normalization factor increase by 18%, from 2.00×10^5 curies for the PAVT to 2.36×10^5 curies for the AMWTP waste. This increase implies that there will be a small decrease in normalized releases from the repository. The decrease will be small because the INEEL waste accounts for less than 10% of the TRU curies in the total inventory for the PAVT.

Table 4. Radionuclide Inventories for CH TRU Waste Streams at INEEL

Radionuclide	PAVT Inventory (Curies)	AMWTP Inventory for Nondebris Wastes (Curies)	AMWTP Inventory for Debris Wastes (Curies)	Total AMWTP Inventory (Curies)
Am-241	*9.01E+04*	*5.84E+04*	*7.60E+03*	*6.60E+04*
Am-243	*3.80E-01*	*2.46E-01*	*6.40E-03*	*2.53E-01*
Np-237	*8.53E-01*	*5.53E-01*	*1.92E-01*	*7.45E-01*
Pu-238	*5.98E+04*	*3.88E+04*	*5.46E+04*	*9.45E+04**
Pu-239	*4.01E+04*	*2.60E+04*	*1.77E+03*	*6.57E+04**
Pu-240	*9.82E+03*	*6.36E+03*	*9.92E+02*	*9.76E+03**
Pu-241	1.50E+05	9.72E+04	4.20E+00	9.72E+04
Pu-242	9.45E-01	6.12E-01	1.35E-01	7.47E-01
Th-232	3.30E-01	2.14E-01	6.56E+00	6.78E+00
U-233	8.99E+02	5.83E+02	8.48E+02	1.43E+03
U-235	6.17E-02	4.00E-02	7.85E-02	1.19E-01
U-238	1.16E-01	7.52E-02	2.27E-02	9.79E-02
Pu-52 Weapons Grade Pu:				
Pu-239 - 94%	---	---	*3.77E+04*	
Pu-240 - 6%	---	---	*2.41E+03*	
Pu-83 Heat Generating Pu:				
Pu-238 - 80%	---	---	*1.17E+03*	
Pu-239 - 16%	---	---	*2.35E+02*	
Totals	3.51E+05	2.27E+05	1.07E+05	3.35E+05

*These values include the Pu isotopes for the Pu-52 and Pu-83 waste forms.

2.4 CPR Inventory from AMWTP Waste

The inventory of cellulosics, plastics and rubbers (CPR) in the waste is particularly important for determining future repository states in which biodegradation is possible. The inventory of CPR in the CH TRU waste streams from INEEL is therefore analyzed for the PAVT and for AMWTP. Inventory information for the PAVT is based on the Transuranic Waste Baseline Inventory Report (DOE 1996b) and the CCA (DOE 1996a); inventory information for AMWTP waste is based on preliminary information from INEEL for the CRA inventory update.

For the PAVT, the stored (existing) volume of CH TRU wastes at the INEEL was 28,607 m^3 (DOE 1995). The projected (future) volume of INEEL waste was zero. The total disposal volume of CH TRU wastes from INEEL for performance assessment was then 28,607 m^3. The mass of CPR in CH TRU wastes from INEEL is calculated in Table 5 for the stored, projected, and disposal inventories, based on the average density of cellulosics, plastics and rubbers, weighted over ten final waste forms (DOE 1995, Tables 3-1 through 3-11).

The calculation of the total mass of CPR in the repository for the PAVT is illustrated in Table 6, based on data in Table 6-10 of the CCA (DOE 1996a). The mass of CPR in Table 6 is the basis for the inventory of CPR for performance assessment for the PAVT.

Table 5. Mass of CPR in CH TRU waste at the INEEL for the PAVT

	Volume (m^3)	**Average Density of Cellulosics in Waste (kg/m^3)**	**Average Density of Plastics in Waste (kg/m^3)**	**Average Density of Rubbers in Waste (kg/m^3)**	**Mass of CPR (kg)**
Stored Waste	28,607	98.8	66.0	19.8	5.28×10^6
Projected Waste	0.0	0.0	0.0	0.0	0.0
Disposal Waste	28,607	98.8	66.0	19.8	5.28×10^6

Table 6. Total Masses of CPR for the PAVT

	Volume (m^3)	**Average Density of Cellulosics in Waste (kg/m^3)**	**Average Density of Plastics* in Waste (kg/m^3)**	**Average Density of Rubbers in Waste (kg/m^3)**	**Total Mass of CPR (kg)**
CH TRU	168,500	54	34 + 26	10	2.09×10^7
RH TRU	7,080	17	15 + 3.1	3.3	2.72×10^5
Total	175,000	---	---	---	2.12×10^7

*The two entries in this column account for the density of plastics in the waste and the bulk density of plastic liners.

Finally, the average density of CPR in CH TRU waste for the PAVT without the INEEL waste is calculated as follows:

$$\frac{2.09\times10^7 kg - 5.28\times10^6 kg}{168500m^3 - 28607m^3} = 112 \text{ kg/m}^3,$$

where the values for the total mass and total volume of CPR in CH TRU are taken from Table 6 and the mass and volume of CPR in INEEL CH TRU waste are taken from Table 5.

The AMWTP will process and supercompact 46,461 m^3 of CH TRU debris wastes (CRA inventory update from INEEL). This volume is greater than the inventory volume from INEEL for the PAVT, which was 28,607 m^3 (see Table 5). The increase in volume is the result of different processing assumptions for the waste streams. For the PAVT, the INEEL waste volume assumed that a separation process would reduce the total volume of waste sent to the WIPP. The separation process has been replaced by supercompaction of debris waste in the AMWTP.

The AMWTP is also planning to direct-ship 18,539 m^3 of non-debris wastes that are primarily sludges (CRA inventory update from INEEL). The sludges will not be compacted and have essentially zero mass of cellulosics, plastics, and rubbers.

The debris waste will be supercompacted to a final waste form volume of 11,635 m^3 (CRA inventory update from INEEL). The average densities of cellulosics, plastics, and rubbers in the compacted debris waste form are estimated to be 517 kg/m^3, 349.4 kg/m^3, and 136.5 kg/m^3, respectively (CRA inventory update from INEEL). The total mass of CPR in the debris wastes is then 1.17×10^7 kg (see Table 7). There is no CPR in the nondebris waste (sludges), so the total mass of CPR from AMWTP waste will be 1.17×10^7 kg.

Table 7. Mass of CPR in Wastes Processed by the AMWTP

	Volume (m^3)	Average Density of Cellulosics in Waste (kg/m^3)	Average Density of Plastics in Waste (kg/m^3)	Average Density of Rubbers in Waste (kg/m^3)	Total Mass of CPR (kg)
Supercompacted Waste	11,635	517	349.4	136.5	1.17×10^7
Uncompacted Waste	18,539	0	0	0	0
Totals	30,174	---	---	---	1.17×10^7

These inventory data are used in Section 3.3 to evaluate the change in mass of CPR for a repository with AMWTP waste.

3.0 IMPACTS ON THE PHYSICAL ENVIRONMENT

3.1 Number of Drums and Containers

A repository with AMWTP waste will include randomly distributed three-packs of 100-gallon containers in place of seven-packs of 55-gallon drums. Assuming that a total of 3,496 shipments of supercompacted AMWTP waste (see Table 1) are randomly emplaced in the repository and that each shipment has five three-packs of 100-gallon containers, a total of (5)(3,496) = 17,480 three-packs will be emplaced in the repository. Since each three-pack replaces a seven pack of 55-gallon drums, the AMWTP waste will replace (7)(17,480) = 122,360 55-gallon drums of uncompacted waste. There will be a total of (3)(17,480) = 52,440 100-gallon containers in the repository.

A repository with AMWTP waste will also include drums of non-debris (uncompacted) AMWTP waste that are direct-shipped to WIPP. Assuming a total of 3,833 shipments of uncompacted AMWTP waste (see Table 1) and assuming that each shipment has five seven-packs of 55-gallon drums, a total of (5)(7)(3,833) = 134,155 55-gallon drums of non-debris AMWTP waste will be emplaced in the repository.

Finally, CH TRU waste from other sites will fill the remaining space in the repository. The number of remaining drums is (810,000 - 122,360 - 134,155) = 553,485 drums of non-AMWTP waste. The drum and container inventory for CH TRU wastes in the repository with AMWTP waste is summarized in Table 8. There are a total of 897,400 55-gallon drums in compacted or uncompacted form, assuming an average of four pucks per 100-gallon container.

Table 8. Drum and Container Inventory of CH TRU Wastes for a Repository with AMWTP Waste

Waste Source	Number of Drums or Containers	Percent of CH TRU Waste Volume
Supercompacted AMWTP Waste	52,440 100-gallon containers (replacing 122,360 55-gallon drums)	15.1
Uncompacted AMWTP Waste	134,155 55-gallon drums	16.6
Waste from Other Sites	553,485 55-gallon drums	68.3
Totals	897,400 55-gallon drums in compacted or uncompacted form	100

3.2 Mass of Iron in the Repository

The average mass of iron in each 55-gallon drum of CH TRU waste can be calculated from the PAVT input data as:

$$\frac{((170+139)kg/m^3)(168{,}500\ m^3)}{810{,}000\ Drums} = 64.28 \text{ kg of iron per 55-gallon drum,}$$

where 170 kg/m^3 is the average density of iron-based materials in CH TRU waste and 139 kg/m^3 is the density of iron-based materials in the 55-gallon drums themselves (DOE 1996a, Table 6-

10). So this mass includes both the iron-based materials in the waste and the iron in each 55-gallon drum.

The mass of iron due to remote handled transuranic (RH TRU) waste can be calculated from the PAVT input data as:

$$((100 + 2590) kg/m^3)(7{,}080\ m^3) = 1.90 \times 10^7 \text{ kg of iron from RH TRU,}$$

where 100 kg/m^3 is the average density of iron-based materials in RH TRU waste and 2,590 kg/m^3 is the density of iron in the waste boxes (DOE 1996a, Table 6-10).

Each 100-gallon container weighs 95 pounds (43.1 kg) empty. The total mass of iron in the CH TRU waste in the repository with AMWTP waste can then be calculated as:

$$\begin{aligned} \textit{Mass of Iron} &= (64.28\, kg/drum)(897{,}400\ drums) + (43.1\, kg/overpack)(52{,}440\, overpacks), \\ &= 5.77 \times 10^7\ kg + 2.26 \times 10^6\ kg, \\ &= 6.00 \times 10^7\ kg, \end{aligned}$$

where the first term represents the mass of iron in the CH TRU waste and 55-gallon drums and the second term represents the mass of iron for the 100-gallon containers. The total projected mass of iron from both CH TRU and RH TRU waste in the repository with AMWTP waste is then 7.90×10^7 kg.

The mass of iron in CH TRU waste for the PAVT, with 810,000 55-gallon drums, is (64.28 kg/drum)(810,000 drums) = 5.21×10^7 kg. The total mass of iron in both CH TRU and RH TRU in the PAVT repository is then 7.11×10^7 kg. It follows that the repository with AMWTP waste has 11% more mass of iron than the PAVT repository.

The increase in the mass of iron is beneficial for satisfying the regulatory requirement for a minimum mass of ferrous metals in the repository. This lower limit, 2×10^7 kg, is defined in Table 4-10 of the CCA (DOE 1996a). The total projected mass of iron in a repository with AMWTP waste, 7.90×10^7 kg, is almost four times greater than this minimum value.

The impact on gas pressure from the presence of additional iron-based materials for the repository with AMWTP waste is expected to be minimal because there is an excess of iron-based materials in the PAVT. The amount of iron-based materials remaining in the repository after 10,000 years ranges from 28% to 98% of the initial inventory for the PAVT (DOE 1997, Appendix A, Section A.1.1.1.1); however, the iron-based materials in the waste panel are completely depleted in three realizations (DOE 1997a, Appendix A, Section A.1.1.1.1). The inventory of iron is depleted faster in the waste panel than in the total repository because inundated conditions are required for corrosion and because the average brine saturation is greater in the waste panel than in the total repository. The inventory of iron-based materials in the PAVT is therefore not depleted after 10,000 years in almost all realizations, so adding more iron will have little impact on the generation of hydrogen gas by corrosion. In fact, the additional iron is generally beneficial because it helps to ensure reducing chemical conditions will be maintained in the repository, as explained in Section 3.5.

3.3 Mass of Cellulosics/Plastics/Rubbers in the Repository

Table 9 summarizes the calculations for the mass of cellulosics, plastics, and rubbers (CPR) for a repository with AMWTP waste. The mass of CPR in the compacted debris wastes from the AMWTP is 1.17×10^7 kg, and the mass of CPR in the non-debris wastes from the AMWTP is zero, as shown in Table 7. The mass of CPR in the non-AMWTP waste from other sites is (0.683)(168,500 m^3)(112 kg/m^3) = 1.29×10^7 kg, based on the percent of the repository filled with CH TRU from other sites (see Table 8) and the average density of CPR in this waste (see Section 2.2). It follows that the total projected mass of CPR at repository closure is 2.46×10^7 kg with AMWTP waste. Since the PAVT has 2.09×10^7 kg of CPR in CH TRU waste (see Table 6), the repository with AMWTP waste has 18% more mass of CPR in CH TRU waste than the PAVT repository.

Table 9. Calculation of Waste Volumes and CPR Masses in the Repository with AMWTP Waste

Waste Source	Mass of CPR (kg)	Comment
Supercompacted AMWTP Waste	1.17×10^7	See Table 7
Uncompacted AMWTP Waste	0.0	See Table 7
CPR from Other Sites	(0.683)(168,500 m^3)(112 kg/m^3) = 1.29×10^7 kg	See Table 8 for the percent of CH TRU volume available
Totals	2.46×10^7 kg	100

This increase brings the projected mass of CPR at repository closure to 2.46×10^7 kg, a value that is greater than the maximum limit of 2×10^7 kg defined in the CCA (DOE 1996a, Table 4-10) and greater than the mass of CPR in the PAVT, 2.12×10^7 kg. The DOE will use the WIPP Waste Information System to track the emplaced mass of CPR against the repository limit and the emplaced mass of CPR will not reach the maximum limit for many years. Given these facts, the DOE is not requesting an increase in the maximum limit of CPR from the EPA at this time.

The increased mass of CPR could increase gas pressure in some realizations, but should have little impact on normalized releases. The impact from additional CPR materials in the repository with AMWTP waste would be that more moles of gas will be generated than in the PAVT. Since gas can flow freely between panels for the PAVT, it follows that the increased gas generated by microbial processes will be spread uniformly across the repository. This will result in repository pressures that could be higher than predicted by the PAVT for realizations with microbial degradation. The quantitative increase will vary with the process generating the gas:

- 50% of the PA realizations do not have microbial degradation. The increase in CPR mass has no impact whatsoever on gas pressure in these realizations because all gas is generated by corrosion.

- 25% of the realizations have corrosion and microbial degradation of cellulosics alone. These realizations will tend to increase in pressure by up to 18%. However, the key issue for normalized release is the number of realizations with pressure above 8 MPa, the threshold for a spallings release. A horsehair plot of pressure in the waste panel for the undisturbed PAVT scenario (DOE 1997a, Appendix A, Figure A.1-2) demonstrates that many of the higher pressure realizations are above 8 MPa by 2,000 years. Since the most likely number of borehole intrusions into the repository is five (DOE 1996a, Figure 6-27), the average time for the first drilling intrusion is about 2,000 years and any effect from increased pressure on spallings will affect relatively few of the realizations with microbial degradation of cellulosics, which tend toward higher pressures than the realizations with only corrosion.

- 25% of the realizations have corrosion and microbial degradation of cellulosics, plastics, and rubbers. The pressure in these undisturbed PAVT realizations increases rapidly during the first 500 years because of high gas generation rates coupled with creep closure (DOE 1997a, Appendix A, Section A.1.1.1 and Figure A.1-2). Most high pressure realizations will exceed 8 MPa before 1,000 years, based on Figure A.1-2, so further increases in pressure will have little impact on normalized release. In addition, these realizations can have only a modest increase in pressure above the PAVT because they are already near or at lithostatic pressure, and any substantial increase in gas pressure above lithostatic will be relieved by fracturing and increased porosity in the disturbed rock zone and/or the anhydrite interbeds.

The conclusion is that few realizations in a performance assessment are likely to see an increase in gas pressure above the 8 MPa threshold for spallings due to additional mass of CPR.

Panel closure design may affect the permeability of these closures. A closure with low permeability can limit the ability of gas to flow through the closures and increase the time required for pressure to equilibrate between adjacent panels. Detailed PA analysis of panel closure designs for the PAVT with and without a low permeability panel closure design (called Option D) demonstrated that there is very little sensitivity of normalized release to closure permeability within a broad range of values (10^{-15} m^2 to 10^{-19} m^2) (DOE 2002c, Attachment C). The rationale for this insensitivity is as follows:

(1) Cuttings/cavings release is completely independent of pressure,

(2) Spallings occurs only when the repository pressure exceeds 8 MPa at the time of intrusion. The volume of spalled material is then independent of repository pressure. Since most realizations where biodegradation is active already have enough CPR to raise the pressure above 8 MPa, it follows that adding more CPR will not change spallings releases on a first intrusion. Spallings releases on the second and third intrusions into the PAVT repository generally have limited impact on long-term performance because bleed-off of gas pressure through degraded boreholes reduces repository pressure below the 8 MPa limit to initiate a spall. Tight panel closures delay the bleed-off of gas pressure in the unintruded panels by several thousand years (DOE 2002c, Attachment C), but gas pressure eventually falls below the 8 MPa threshold for spallings release.

Given these results and the fact that cuttings/cavings and spallings are the major release mechanisms from the repository, the change in the mass of CPR for the repository will not have a significant adverse impact on the normalized release from the repository. The insensitivity of normalized release to gas generation was also confirmed by sensitivity analyses for the CCA (DOE 1996a, Appendix WCL, Sections WCL.2 and WCL.3).

While normalized release is not sensitive to the presence of additional mass of CPR, more CPR can have an impact on the amount of magnesium oxide required to sequester carbon dioxide, thereby buffering brine pH within a beneficial range for actinide solubility. The impact of this additional mass on the compliance margin for magnesium oxide is discussed in Section 3.5.

3.4 Compaction of the Waste Form

The AMWTP will compact 55-gallon drums of debris waste before they are emplaced in the repository. This compaction process produces results that are similar to the *in situ* waste compaction that will be caused by creep closure of salt around the individual rooms and access drifts of the WIPP, as demonstrated below. In this circumstance, it is likely that the final end state of waste will be similar for the PAVT or the repository with AWMTP waste, although the path to the end state may be different. The final end state, as used here, refers to intrinsic material properties such as waste density, waste porosity, and waste shear strength. Extensive parameters, such as the height of a compacted room, will be different, as explained below.

Table 10 presents an analysis of the waste porosity in the PAVT calculations for the undisturbed scenario. The PAVT results demonstrate that waste porosity reaches a minimum value of 7% to 22% of the initial excavated volume (DOE 1997a, Appendix A, Section A.1.1.1.2) between 500 and 1,000 years, and may increase by a small amount afterwards (DOE 1997a, Appendix A, Figure A.1-20). This porosity from the PAVT is referred to as the BRAGFLO porosity because it is referenced to the initial excavated volume of the room.

Table 10. Waste Compaction Ratios for the Undisturbed Scenario of the PAVT and for the AMWTP

Parameter Description	Minimum Value	Maximum Value
BRAGFLO Porosity, ϕ_B	0.07	0.22
Room Height, h (meters)	0.878	1.47
Drum Compaction Ratio*, *In Situ* Process	0.328	0.550
Compaction Ratio, AMWTP	0.273	0.636

*Compaction ratio = compacted room height/initial height of 3 55-gallon drums = $h/2.68$

The BRAGFLO porosity values can be used to calculate the corresponding height change of a 55-gallon drum from room closure. The appropriate relation to calculate the room height, h, is:

$$h = h_0(1 - \phi_0 + \phi_B),$$

where ϕ_B, is the BRAGFLO porosity, ϕ_0 is the initial waste porosity (0.848), and h_0 is the initial room height (3.96) meters. The BRAGFLO porosity is defined as the void volume divided by the original (total) volume of a control volume. The drum compaction ratio for the *in situ* process is calculated by dividing the room height, h, by the initial height of a 3-high stack of 55-gallon drums, 3 × 0.893 m or 2.68 meters. The presence of mylar spacers and pallets is ignored here.

The AMWTP compacts 55-gallon drums to a final volume of approximately 15 gallons to 35 gallons, or a volume compaction ratio (compacted volume to initial volume) of 0.273 to 0.636. As shown by the last two lines in Table 10, the range of volume compaction ratios for the *in situ* process is within the range of values for the AMWTP.

Given the similarity of waste compaction ratios for the AMWTP and from *in situ* creep closure, it is reasonable to expect that the PAVT properties and distributions for waste density, waste shear strength, and waste permeability will be unchanged and directly applicable to the AMWTP-processed wastes. The *in situ* creep closure process is complex because it is a function of gas pressure. Many realizations with high gas pressure would shift the *in situ* compaction ratios to the higher range of values, i.e., to the less compacted case. But as noted in Section 3.3, 75% of the realizations in performance assessment will experience little or no change in gas pressure in spite of the presence of additional mass of CPR in the repository. It follows that the room closure process will drive the waste in uncompacted 55-gallon drums to similar end states, with similar ranges of hydrologic and mechanical properties, as the waste that is initially compacted in the AMWTP in the majority of cases.

This result also implies that the porosity surface (DOE 1995a, Appendix PORSURF) will have similar end states for the PAVT or for the repository with AMWTP waste. The porosity surface is a look-up table that provides BRAGFLO with the value of porosity as a function of pressure and time for each zone or cell in the grid. It is based on detailed calculations with a geomechanics code, SANTOS, using a variety of gas generation rates. The porosity surface should have similar end states because the final waste form compaction ratios are very similar for the PAVT or for the repository with AMWTP waste.

There will be differences in parameters such as panel height due to the presence of supercompacted waste. In particular, a column of waste with three 55-gallon drums should compact to about one-half of the room height for a column of waste with two 55-gallon drums and one 100-gallon container of supercompacted waste. In the first case, there will be three compressed drums after room closure, while in the second case there will be six compressed drums after room closure. While the density and porosity of the compressed waste will be similar, the final height of the room may be greater because of the initial compacted waste state in the 100-gallon drums. The potential impact of a taller stack of compacted drums on release from cuttings/cavings is discussed in Section 4.1.

3.5 Chemical Environment in the Repository

The solubility calculations for the major radionuclides in WIPP waste assume that a reducing environment with a stable pH will be maintained in the repository. This assumption is supported by two factors: (1) the amount of iron in the waste, and (2) the availability of magnesium oxide to sequester carbon dioxide generated during microbial degradation.

With regard to the amount of iron, the presence of the 100-gallon containers adds additional iron to the repository with AMWTP waste. Since the 55-gallon drums are included in the AMWTP supercompaction process, the ratio of iron mass to waste mass remains unchanged for the supercompacted waste. The presence of the 100-gallon containers adds a small amount of iron, on the order of 4%, to the amount of iron in the 55-gallon drums. This additional iron will increase the ratio of iron mass to waste mass by a small amount, and the reducing effect of iron will therefore remain unchanged or increase slightly.

Magnesium oxide is included in the WIPP repository to sequester carbon dioxide. To be effective, magnesium oxide must react with carbon dioxide produced by microbial degradation, thereby controlling the P_{CO_2} and pH of WIPP brines within ranges that are favorable from the standpoint of actinide solubilities. In the CCA, the DOE proposed to emplace 77,640 metric tons of magnesium oxide in the repository. The DOE asserted that this is at least 3.7 times the mass required to consume all of the carbon dioxide, based on the quantities of CPR to be emplaced in the WIPP, and the assumptions that microbial activity could consume all of the CPR in the waste and that methanogenesis would be the dominant respiratory pathway.

In the Certification Decision; Final Rule (EPA, 1998), the EPA approved the emplacement of 77,640 tons of magnesium oxide in the repository. The EPA determined that this is 1.95 times the mass required to consume all of the carbon dioxide, based on the quantities of CPR and the assumptions that microbial activity could consume all of the CPR in the waste and that denitrification, rather than methanogenesis, would be the dominant respiratory pathway. The EPA value (1.95) is a minimum estimate because significant microbial gas generation in the repository is possible but by no means certain, and because microbial activity will probably not consume all of the CPR even if it does occur.

Methanogenesis has been observed under several combinations of conditions since the CCA was prepared. It is now clear that, if significant microbial activity occurs, methanogenesis would be the dominant respiratory pathway as postulated in the CCA. These new data are based on microbial gas production up to 3,009 days under humid conditions and 3,464 days under inundated conditions. With these new results (SNL, 2002b), the assumptions used to calculate a compliance margin of 3.7 are now even more defensible.

In July 2000, the DOE proposed a minor change in the emplacement scheme for magnesium oxide backfill. The mini sacks of magnesium oxide would be eliminated, primarily to reduce the risk of injury associated with manual emplacement of these sacks. The EPA approved this change in January 2001. Elimination of the mini sacks has resulted in a 15% reduction in the total mass of magnesium oxide to be emplaced in the repository, and has reduced the compliance margin from 1.95 to 1.67, or from 3.7 to 3.2, depending on the assumptions used to calculate this parameter.

The projected mass of CPR in the repository with AMWTP waste could increase by 18% in comparison to the PAVT, as shown in Section 3.3. This increase brings the projected mass of CPR at repository closure to 2.46×10^7 kg, a value that is greater than the maximum limit of 2×10^7 kg for CPR in the CCA (DOE 1996a, Table 4-10). The total emplaced mass of CPR will not reach this limit for many years and cannot be exceeded without prior approval from the EPA; the DOE is not requesting such a change at this time. If the EPA were to approve an increase in the maximum limit on CPR, this new maximum value would reduce the compliance margin from 1.67 to 1.42, or from 3.2 to 2.7, depending on the assumptions used in its calculation. The latest experimental data support methanogenesis as the dominant respiratory pathway, implying that the compliance margin will be greater than the present EPA estimate.

3.6 Formation of Colloidal Suspensions

The impact of colloids on performance assessment is a function of three factors: (1) the concentration of colloids in the repository and groundwater, (2) the ability of radionuclides to adsorb onto the colloids that are present, and (3) the long-term stability of colloids. These three factors are a function of the chemical environment in the repository. The presence of additional iron in the AMWTP containers will help to maintain a reducing environment in the panels and the presence of sufficient magnesium oxide helps to buffer the pH of brine solutions within a known range. These effects help to maintain a similar chemical environment to that for the PAVT and therefore a similar environment for sorption of actinides onto colloids and for long-term stability of colloids.

3.7 Summary of Impacts on Waste Characteristics

The assessment of the potential impacts from AMWTP waste on the physical environment demonstrated the following results:

- The mass of iron-based materials in CH TRU and RH TRU wastes increases by 11% in a repository with AMWTP waste in comparison to the PAVT. The increased mass of iron will have little impact on gas pressure because there is already an excess of iron-based materials in the repository.

- The mass of CPR in the repository with AMWTP waste could increase by 18% in comparison to the PAVT. The impact of the increased mass of CPR on gas pressure will depend strongly on the mechanisms generating the gas:

    - 50% of the PA realizations do not have biodegradation - gas is only generated by corrosion. The amount of CPR has no impact on these realizations.

    - 25% of the PA realizations have corrosion and biodegradation of cellulosics, plastics and rubbers. These realizations have gas pressure above 8 MPa and are near the lithostatic stress beyond 1,000 years. A further increase in the mass of CPR will have very limited impact on normalized release because pressure is above the 8 MPa threshold necessary for spallings. In addition, fracturing in the disturbed rock zone and anhydrite interbeds will provide additional porosity that limits gas pressure to near the lithostatic stress.

    - 25% of the PA realizations have corrosion and biodegradation of cellulosics alone. An increase in the mass of cellulosics will increase gas pressure, but it will have little effect on normalized releases because cuttings/cavings is completely independent of pressure and because most realizations are expected to be above the 8 MPa threshold for spallings by 2,000 years, the average time for the first borehole intrusion.

- Supercompaction of debris waste will have little impact on the parameter values or distributions for final waste density; waste shear strength, and waste permeability, and on the porosity surface because the range of final compacted waste volumes from the AMWTP and from the *in situ* room closure process are in a similar range.

- The repository will still maintain a reducing environment because the mass of iron increases slightly relative to the mass of waste.

- The compliance margin for MgO will remain at 1.67, the current baseline value, unless the DOE requests and the EPA approves an increase in the maximum limit of 2×10^7 kg of CPR in the repository. If the maximum limit on CPR is raised to 2.46×10^7 kg, the compliance margin for MgO would be reduced from 1.67 to 1.42. Sufficient MgO would still be available to sequester all carbon dioxide generated by microbial degradation even with the very conservative assumptions in the current baseline.

- AMWTP waste will have little impact on colloidal suspensions because the additional iron in AMWTP containers and the presence of MgO will help to maintain a similar chemical environment to that for the PAVT. Under these conditions, the concentration of colloids and their ability to transport radionuclides are unchanged.

Table 11 summarizes these impacts in terms of the six waste characteristics that are important to long-term performance of the disposal system.

Table 11. Summary of Impacts from AMWTP Waste on the Six Waste Characteristics Important to Long-Term Performance

Waste Characteristic	Impact of the Supercompaction Process on Long-Term Performance
Solubility	No impact on solubility because: 1. A reducing environment will be maintained, and 2. There is enough magnesium oxide to maintain the current compliance margin of 1.67 with the maximum limit of 2×10^7 kg for CPR. If the maximum limit on CPR is increased (subject to future EPA approval) to the projected mass of CPR with AMWTP waste, 2.46×10^7 kg, the compliance margin for MgO would be reduced from 1.67 to 1.42. Sufficient MgO would still be available to sequester carbon dioxide generated by biodegradation, even with the conservative assumptions in the calculation of the compliance margin.
Formation of colloidal suspensions	The presence of a reducing environment in the repository and the presence of sufficient MgO to buffer the pH of brine solutions will maintain a similar chemical environment to that assumed for the PAVT. The survivability of colloids and their ability to transport radionuclides is unchanged.
Gas generation	The additional mass of iron introduced into the repository will have a minor impact on gas generation because most realizations for the PAVT already have excess iron in the inventory. The additional mass of CPR present in the repository will have no adverse impacts on normalized releases from the repository because normalized release is insensitive to the changes in gas

Waste Characteristic	Impact of the Supercompaction Process on Long-Term Performance
	pressure due to AMWTP waste.
Shear strength of waste	The distribution for shear strength of the waste will remain essentially unchanged because the compacted end states from *in situ* room closure and from supercompaction are in a similar range.
Radioactivity of specific isotopes	The total curies from INEEL decrease by 5% between the INEEL inventory for the PAVT and for the AMWTP. This minor change will be accounted for in inventory updates for future performance assessments. The 5% change in activity will have negligible impact on long-term performance.
TRU activity at disposal	The waste unit normalization factor will increase by 18% between the INEEL inventory for the PAVT and for the AMWTP. This increase will decrease the normalized releases from the repository by a few percent.

4.0 IMPACTS ON NORMALIZED RELEASES

4.1 Cuttings/Cavings Release

The cuttings/cavings process defines part of the direct release of radionuclides when an intrusion borehole passes through the repository. The cuttings/cavings process has two components: (1) the waste directly beneath the drill bit is ground up and transported to the surface in the circulation of the drilling mud (called cuttings), and (2) the circulating mud may scour additional waste from the walls of the borehole (called cavings); this waste is then transported to the surface via the circulation of drilling mud.

The mathematical model for cuttings/cavings in the PAVT is independent of the gas pressure, waste porosity, and brine saturation in the panel. The release volume for cavings depends on the shear strength of the waste, on the average areal loading of radioactivity (i.e., average curies per square meter) at the time of the intrusion, and on the variability of activity among individual waste streams. Since the shear strength of the waste is expected to be the same for the PAVT and for the repository with AMWTP waste (see Section 3.4), this discussion focuses on the difference in areal loading between the PAVT and the repository with AMWTP waste.

The cuttings/cavings model for the PAVT assumes that a borehole intersects three drums for the release calculation. Each drum is assumed to contain a single waste stream and the average activity of the three intersected waste streams determines the normalized activity for the intrusion. Individual 55-gallon drums, overpacks, standard waste boxes, or any gaps between drums are not directly represented in performance assessment. In the future, the presence of 100-gallon containers will be represented as a new waste stream that has its own time-dependent decay of activity. The volume and activity of this waste stream will be tracked, rather than that of the individual pucks, because it is unnecessary to evaluate releases at this level of detail.

With AMWTP waste, a borehole may pass through three layers of 55-gallon drums or 100-gallon containers, depending on the configuration beneath the drillbit. The following discussion demonstrates that the addition of 100-gallon drums with supercompacted AMWTP waste does not impact the assumptions in PA relating to the emplaced configuration of waste streams. In other words, PA treats an intrusion as a borehole intersecting waste streams, not drums or containers, so representation of the 100-gallon drums as a single waste stream is appropriate for calculating normalized releases from cuttings/cavings.

The potential change in normalized release when 100-gallon containers are present is limited by two factors: (1) the FGE limits for the shipping package, and (2) the probability of hitting a 100-gallon container. Each shipping package has a ^{239}Pu fissile gram equivalent limit of 325 grams. This means that the maximum average radionuclide loading for a three-pack of 100-gallon containers will be similar to the maximum average radionuclide loading for a seven-pack of 55-gallon drums. Another way to state this is that the average maximum areal loading of radioactivity for the three-pack will be similar to that of a seven-pack on the size scale of their footprint, even though the three-pack has more compressed drums than the seven-pack.

With regard to the second factor, the consequence from a borehole intrusion is a function of both the volume of waste released and its activity, which depends on the probability of intrusion into the various waste streams. It can be demonstrated that the mean normalized activity released from a borehole intrusion into a repository with random waste emplacement or with non-random waste emplacement is the same. The only constraint on this analysis is that the total normalized activity must remain constant and the total emplacement area must remain constant. Note that performance assessment does not calculate to this level of detail, but the following analysis justifies the use of average waste loadings in PA and tracking waste streams at the drum and container level, rather than for individual pucks.

The following analysis illustrates the equivalence of mean normalized release for random and nonrandom waste emplacement, using a repository with five waste emplacement areas that represent typical emplacement schemes. Assume that there are five regions in the repository with the properties shown in Table 12. The first region represents waste in the PAVT configuration (three layers of 55-gallon drums). Regions 2 through 4 correspond to different configurations with one, two, or even three 100-gallon containers. Region 5 corresponds to a borehole that entirely misses the 100-gallon containers (refer to Figure 3, noting the large void spaces between the three-packs). The normalized activity is the activity at the time of the borehole intrusion.

Table 12. Definition of Waste Emplacement Regions for Non-Random Emplacement

Region No.	Description of Emplacement Scheme	Emplacement Area (m^2)	Normalized Activity (-)
1	3 55-gallon drums (uncompacted)	A_1	NA_1
2	2 55-gallon drums plus 1 100-gallon container	A_2	NA_2
3	1 55-gallon drum plus 2 100-gallon containers	A_3	NA_3
4	3 100-gallon containers	A_4	NA_4
5	No drums (space between three-packs)	A_5	NA_5

The problem is constrained in only two ways: the total area, A_{TOT}, is constant, and the total normalized activity, NA_{TOT}, is constant. The area removed by cuttings/cavings due to the borehole intrusion is defined as A_{CC}.

The mean normalized release, $\overline{R}$, for the non-random emplacement scheme is given by the sum of the probability of hitting a region times the normalized activity released by the hit. The mean normalized release is then given by:

$$\overline{R} = \frac{A_1}{A_{TOT}} NA_1 \frac{A_{CC}}{A_1} + \frac{A_2}{A_{TOT}} NA_2 \frac{A_{CC}}{A_2} + \frac{A_3}{A_{TOT}} NA_3 \frac{A_{CC}}{A_3} + \frac{A_4}{A_{TOT}} NA_4 \frac{A_{CC}}{A_4} + \frac{A_5}{A_{TOT}} NA_5 \frac{A_{CC}}{A_5},$$

where A_i/A_{TOT} is the probability of hitting the i^{th} region, NA_i is the normalized activity in the i^{th} region, and A_{CC}/A_i is the fraction of the activity in the i^{th} region that is released by cuttings/cavings due to the borehole intrusion. Canceling the common value of A_i in each term on the right-hand side,

$$
\begin{aligned}
\overline{R} &= \frac{NA_1 A_{CC}}{A_{TOT}} + \frac{NA_2 A_{CC}}{A_{TOT}} + \frac{NA_3 A_{CC}}{A_{TOT}} + \frac{NA_4 A_{CC}}{A_{TOT}} + \frac{NA_5 A_{CC}}{A_{TOT}}, \\
&= \frac{(NA_1 + NA_2 + NA_3 + NA_4 + NA_5) A_{CC}}{A_{TOT}}, \\
&= \frac{NA_{TOT} A_{CC}}{A_{TOT}}.
\end{aligned}
$$

The final equation for $\overline{R}$ is identical to the mean normalized release if the total normalized activity, NA_{TOT}, is randomly distributed over the total emplacement area, A_{TOT}.

This result demonstrates that the mean normalized release is the same for random or nonrandom waste emplacement. It also demonstrates that the presence of compressed pucks in 100-gallon containers will not change the mean normalized release from cuttings/cavings, provided the total activity and total emplacement area remain unchanged. Note that the total activity for AMWTP waste from INEEL actually decreases by 5% in comparison to the PAVT, as shown in Table 4.

The above result will be valid at each of the discrete times for which a borehole intrusion occurs and hence will remain true for a sequence of boreholes intruding into the repository with time-dependent normalized activities. Similarly, this result will hold for the specific value of the cavings area and the associated value of the shear strength of the waste in a given realization of the PA calculations.

The above derivation applies to the mean normalized release. The complementary cumulative distribution function (CCDF) for cuttings/cavings also includes more extreme but lower probability cases. It is likely that the presence of 100-gallon containers will not significantly change these extremes. First, the radionuclide inventory for the INEEL waste is almost unchanged between the PAVT inventory and the AMWTP (see Section 2.3). Second, the amount of TRU radionuclides has increased so the waste unit normalization factor will decrease, reducing normalized activity for a given inventory. It therefore appears unlikely that the presence of 100-gallon containers will substantially increase the normalized release for extreme cases.

In summary, the mean normalized release from cuttings/cavings will not change significantly between the PAVT and the repository with AMWTP waste because mean normalized release is the same for random or nonrandom waste emplacement, because the distribution for the waste shear strength should be essentially unchanged from the PAVT, and because the fissile gram equivalent limits for the transporter constrain the variability between maximally loaded three-packs and seven-packs.

4.2 Spallings Release

A direct intrusion into CH TRU waste can also produce a release of waste due to spallings. The spallings process defines the erosion, lofting, and transport of solid waste particulates toward and up a borehole due to rapidly flowing gas after an intrusion into a high pressure repository. While a mathematical model for spallings was developed for the CCA, the PAVT has a simple bounding approximation that assumes that 0.5 m^3 to 4.0 m^3 of uncompressed waste will be released by spallings whenever the panel pressure is greater than 8 MPa at the time of the intrusion. The magnitude of the spallings volume (0.5 to 4.0 m^3) is completely independent of the state of the repository at the time of intrusion, provided that gas pressure exceeds 8 MPa. The activity of the spalled waste is based on the average activity for the total repository and is therefore independent of the emplacement configuration of drums and containers.

The ranges for final waste density and for waste porosity are expected to be similar between the PAVT and the repository with AMWTP waste (see Section 3.4). The repository pressure is anticipated to be similar, as discussed in Sections 3.2 and 3.3. It follows that the presence of AMWTP waste will not cause a significant change in spallings volumes and little change in normalized releases in comparison to the PAVT.

4.3 Direct Brine Release

The presence of AMWTP waste will have no impact on direct brine releases (DBR). DBR is a groundwater-mediated release, driven by the solubilities of the radionuclides and the pressure and saturation in the waste at the time of intrusion. Assuming that solubilities are unchanged (see Section 3.5), that the permeability of the waste remains unchanged (see Section 3.4), and that repository pressures remain similar to the PAVT (see Section 3.3), it follows that the presence of AMWTP waste will cause little change to DBR.

4.4 Long-Term Groundwater Release Through the Culebra

The impacts of AMWTP waste on long-term groundwater releases up boreholes and through the Culebra can be evaluated in much the same fashion as the direct brine releases. That is, releases through the Culebra will be similar to the PAVT because the waste and borehole permeabilities are unchanged, because solubilities are unchanged, and because repository pressure will be similar to the PAVT.

5.0 CONCLUSIONS

The assessment of the potential impacts from AMWTP waste on the long-term performance of the repository demonstrates the following:

- Mass of iron in the repository with AMWTP waste can increase by 11% in comparison to the PAVT. These changes should have minimal impacts on repository pressure and negligible impacts on normalized releases. This change is beneficial for maintaining a reducing environment and for meeting the minimum mass of iron-based materials in the repository (DOE 1996a, Table 4-10).

- The mass of cellulosics, plastics and rubbers (CPR) in the repository with AMWTP waste could increase by 18% in comparison to the PAVT. This increase brings the projected mass of CPR at repository closure to 2.46×10^7 kg, a value that is greater than the maximum limit of 2×10^7 kg for CPR (DOE 1996a, Table 4-10) and greater than the mass of CPR for the PAVT, 2.12×10^7 kg.. The emplaced mass of CPR is tracked in the WIPP Waste Information System and is not projected to reach this limit for many years. This limit cannot be exceeded without prior approval from the EPA, and the DOE is not currently requesting such a change.

- Supercompaction of debris waste will have little impact on the parameter values and distributions for final waste density; waste shear strength, and waste permeability, and on the porosity surface because the final compacted waste volumes from the AMWTP and from the *in situ* room closure process are in a similar range.

- The repository will still maintain a reducing environment because the mass of iron relative to the mass of waste increases slightly.

- The compliance margin for magnesium oxide will remain at 1.67, the currently approved value. If the maximum limit on CPR is raised to 2.46×10^7 kg, the compliance margin for magnesium oxide would be reduced from 1.67 to 1.42. A sufficient quantity of MgO will still be available to sequester the carbon dioxide generated by microbial degradation, even with the conservative assumptions used in the PAVT. In fact, the latest experimental data imply that the compliance margin will approach 3.2 even if the maximum limit on CPR is raised to 2.46×10^7 kg.

- AMWTP waste will have little impact on colloidal suspensions because the additional iron in AMWTP containers and additional magnesium oxide will help to maintain a similar chemical environment to that for the PAVT. Under these conditions, the survivability of colloids and their ability to transport radionuclides is unchanged.

- Normalized releases from cuttings/cavings will not be changed significantly if the total normalized activity of waste in the repository and its footprint are unchanged.

- Normalized releases from spallings will not be changed significantly because the compacted state of the waste is very similar for the PAVT and for the repository with

AMWTP waste and because the changes in gas pressure do not significantly change the number of spallings in comparison to the PAVT.

- Normalized releases from DBR and long-term groundwater releases through the Culebra will be similar to those for the PAVT because the waste and borehole permeabilities are unchanged, because solubilities are unchanged, and because repository pressure will be similar to the PAVT.

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