GTCC LLW ENVIRONMENTAL IMPACT STATEMENT: POST-CLOSURE PERFORMANCE DATA PACKAGE

Waste Isolation Pilot Plant

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1. INTRODUCTION

The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) assigned the United States Federal Government the responsibility for disposing of Greater-Than-Class-C (GTCC) low-level radioactive waste (LLW) generated by activities licensed by U.S. Nuclear Regulatory Commission (NRC) or Agreement States (42 USC 2021 as amended). The LLRWPAA requires that the Federal Government provide for the disposal of GTCC LLW in a facility that adequately protects the safety and health of the public and is licensed by NRC. As part of the responsibilities assigned to the U.S. Department of Energy (DOE) in the LLRWPAA, the DOE has begun the environmental impact statement (EIS) process for development of a disposal capability for GTCC LLW and DOE GTCC-like waste. This document presents data necessary to evaluate the suitability of the Waste Isolation Pilot Plant (WIPP) as a potential site in the GTCC EIS.

1.1 BACKGROUND

1.1.1 GTCC LLW Waste Streams

The NRC classifies LLW in four categories, Class A, Class B, Class C and waste that is not generally acceptable for near-surface disposal, GTCC LLW, as defined in 10 CFR 61.55. LLW that exceeds the maximum concentration limits of radionuclides established by NRC for Class C waste is referred to as "Greater-Than-Class-C". In anticipation of the upcoming GTCC LLW EIS, the DOE has recently (U.S. DOE 2006) prepared an update to their 1994 GTCC LLW inventory estimates, *Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclides, Activities, and Other Characteristics* (DOE/LLW-114) (U.S. DOE 1994). Further, the DOE has established an inventory basis for the GTCC LLW EIS evaluations in Task 3.2 of this project. That inventory basis is documented in *Basis Inventory for Greater-Than-Class-C Low-Level Radioactive Waste Environmental Impact Statement Evaluations* (SNL 2008a) and *Supplement to Greater-Than-Class-C (GTCC) Low-Level Radioactive Waste and U.S. Department of Energy GTCC-Like Waste Inventory Reports* (Argonne 2008).

The inventory documents (SNL 2008a, Argonne 2008), provide information about volumes, radionuclide activities, chemical forms, packages, locations, and disposal rates for four waste streams as summarized in Table 1. The waste streams identified in Table 1 are comprised of waste types that are regulated by the NRC as GTCC LLW, as defined in 10 CFR 61.55 (nuclear utility activated metal, sealed sources, and other waste), or contain DOE waste with characteristics similar to GTCC LLW and which currently do not have an identified path to disposal (referred to in this report as DOE GTCC-like waste). This waste is not regulated by the NRC, but will be included in the EIS evaluations.

Therefore, for this analysis, these waste streams are as follows:

- Waste stream 1 consists of GTCC LLW activated metal from nuclear utilities.

- Waste stream 2 consists of sealed radioactive sources and has been broken down into four waste streams (2a through 2d), by source (DOE versus commercial), by container type and the presence/absence of ^{137}Cs (handling considerations).

- Waste stream 3 represents GTCC-like activated metal from DOE sites.

- Waste stream 4 contains other waste and is broken down by source (DOE versus commercial) and handling considerations (contact-handled [CH] versus remote-handled [RH]).

Table 1. Summary of GTCC LLW and DOE GTCC-like Waste Volumes[a]

Waste Stream	ID	Description	Volume (m^3)	Container Type	Number of Containers
1[b]	Com	GTCC LLW Activated Metal	882	h-SAMC	12,796
2a	Com	GTCC LLW Non-cesium Sealed Sources	652	55-gallon drum	3,133
2b	DOE	DOE GTCC-like Non-cesium Sealed Sources	0.84	55-gallon drum	4
2c	Com	GTCC LLW Cesium Sealed Sources	1,019	Irradiator[c]	1,435
2d	DOE	DOE GTCC-like Cesium Sealed Sources	32.66	Irradiator[c]	46
3[b]	DOE	DOE GTCC-like Activated Metal	12.8	h-SAMC	68
4a	Com	GTCC LLW CH Other Waste	43	55-gallon drum	207
4b	DOE	DOE GTCC-like CH Other Waste-- excl West Valley	34.14	55-gallon drum	165
4b	DOE	DOE GTCC-like CH Other Waste-- West Valley	933	SWB	498
4c	Com	GTCC LLW RH Other Waste	34	h-SAMC	173
4d	DOE	DOE GTCC-like RH Other Waste	1,475	h-SAMC	7,486

[a]All data taken from SNL (2008a) and Argonne (2008); [b]SAMC (Shielded Activated Metal Canister) and AMC (Activated Metal Canister) packages are not suitable for WIPP disposal and will not be considered in this analysis; Activated metals will be disposed in WIPP in h-SAMCs; [c]CIS-US (2006). CH = contact-handled; RH = remote-handled; h-SAMC = half - Shielded Activated Metal Canister; SWB = Standard Waste Box.

The methods and assumptions used to formulate the information summarized in Table 1 are documented in SNL (2008a) and Argonne (2008).

For the GTCC LLW EIS analyses, it is assumed that waste stream 1, GTCC LLW activated metal, will be disposed in WIPP in canisters with outer dimensions of 28 inches diameter and 55 inches length (see Section 2.4.1 in SNL 2008), henceforth referred to as half-Shielded Activated Metal Canisters (h-SAMCs).

Waste stream 2a, GTCC LLW sealed sources containing isotopes other than ^{137}Cs, will be disposed in WIPP in 55-gallon drums (SNL 2008a). The outer dimensions of a 55-gallon drum are 24 inches diameter and 35 inches long (U.S. DOE 2006). Waste stream 2b, DOE GTCC-like sealed sources containing isotopes other than ^{137}Cs, will also be disposed in 55-gallon drums. Waste stream 2c, GTCC LLW sealed sources containing ^{137}Cs, is assumed to be disposed in WIPP in the original package, the Cs irradiator. Waste stream 2d, will also be disposed in the Cs irradiators. It is assumed for the GTCC LLW EIS analysis that the CIS-US Inc. Blood Irradiator Model IBL-437 is representative of the cesium irradiator sources. The outer dimensions of the

CIS-US blood irradiator are 26.4 inches wide by 25.6 inches long by 59.1 inches high (CIS-US 2006).

Waste stream 3 is comprised of DOE GTCC-like activated metal, and will be disposed of in h-SAMCs.

Waste stream 4 consists of other waste, which contains contaminated equipment, debris, trash, scrap metal and decontamination decommissioning waste. Waste stream 4 has been broken down into 4 sub-categories 4a through 4d. Waste stream 4a consists of CH GTCC LLW other waste and is assumed to be packaged in 55-gallon drums. Waste stream 4b contains CH DOE GTCC-like other waste and is assumed to be packaged in 55-gallon drums, except the waste stream 4b West Valley waste, which is assumed to be packaged in standard waste boxes (SWBs) with the dimensions of 36.875 inches high, 54.5 inches wide, and 71 inches long. Waste stream 4c consists of RH GTCC LLW other waste, and waste stream 4d is RH DOE GTCC-like other waste. Waste streams 4c and 4d will be disposed of in h-SAMCs.

The DOE has grouped waste into three categories to analyze the inventory in the GTCC EIS. Group 1, which is addressed in this report, is comparable to the inventory presented in the Notice of Intent (NOI), and consists of waste already in storage or expected to be generated from facilities already in operation. Group 2 represents the additional waste that was identified for inclusion in the EIS after the NOI was published, and consists of waste that may be generated from proposed actions. Group 2 will be addressed in an addendum to this report. Group 3 includes wastes from the proposed Global Nuclear Energy Project (GNEP) programmatic alternatives and from the previously proposed Advanced Fuel Cycle Facility (AFCF) and will be qualitatively addressed in the cumulative impacts section of the GTCC EIS.

1.1.2 WIPP Performance Assessment

The WIPP is located in southeastern New Mexico and operated by the DOE as a disposal facility for transuranic (TRU) waste. The WIPP must comply with various environmental regulations, including 40 CFR 191, Subpart B, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, and 40 CFR 268.6, *Petitions to Allow Land Disposal of a Waste Prohibited Under Subpart C of Part* 268. These regulations require a risk analysis of releases of WIPP waste due to inadvertent human intrusion into the repository during the 10,000-year regulatory period. Sandia National Laboratories (SNL) conducts performance assessments (PAs) of the WIPP using a system of computer codes in order to demonstrate compliance with these regulations.

PA calculations were included in DOE's 1996 WIPP Compliance Certification Application (CCA, U.S. DOE 1996) that was submitted to the EPA and in a subsequent Performance Assessment Verification Test (PAVT, MacKinnon and Freeze 1997a, 1997b, 1997c). Based in part on the CCA and PAVT analyses, the EPA certified the WIPP's compliance in May 1998. On March 26, 1999, the WIPP received its first TRU waste shipment. As required by the WIPP Land Withdrawal Act (Public Law 102-579 [as amended by Public Law 104-201]), the DOE is required to submit documentation of continued compliance to the EPA for the recertification of the WIPP every five years following the first receipt of waste.

In March of 2004, the DOE submitted the 2004 Compliance Recertification Application (CRA-2004, U.S. DOE 2004) to the EPA, and PA calculations were again an integral part of the CRA-2004. During their review of the CRA-2004, the EPA requested an additional performance assessment calculation be conducted with modified assumptions and parameter values (Cotsworth 2005). This PA is referred to as the 2004 Compliance Recertification Application Performance Assessment Baseline Calculation (CRA-2004 PABC, Leigh et al. 2005). When the EPA recertified the WIPP in March of 2006, the CRA-2004 PABC was established as the new WIPP PA technical baseline

The regulatory requirements of the WIPP have determined the conceptual structure of the PA. Probabilistic limits on the cumulative releases of radionuclides to the accessible environment for 10,000 years are set in the regulations. It also sets limits on radiation doses to members of the public in the accessible environment for 10,000 years of undisturbed performance, as well as limiting the radioactive contamination of certain sources of groundwater for 10,000 years after disposal. The following is the central requirement in 40 CFR 191, Subpart B and the primary determinant of the conceptual structure of WIPP PA:

§ 191.13 Containment requirements:

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

(b) Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13(a) will be achieved.

Containment Requirement 191.13(a) refers to "quantities calculated according to Table 1 (Appendix A)," which means a normalized radionuclide release to the accessible environment based on the type of waste being disposed of, the initial waste inventory and the release that takes place. Table 1 (Appendix A) specifies allowable releases (i.e. release limits) for individual radionuclides and is reproduced as Table 2 in this document.

Table 2. 40 CFR 191 Release Limits for Containment Requirements[a]

[Cumulative releases to the accessible environment for 10,000 years after disposal]	
Radionuclide	**Release Limit per 1,000 MTHM or other unit of waste (b) (see notes) (c) (curies)**
Americium-241 or –243	100
Carbon-14	100
Cesium-135 or –137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or –242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or –232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or –238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

Application of Table 1 {Appendix A to Part 191 for Subpart B} 40 CFR 191.

Note 1: Units of Waste. The Release Limits in Table 1 apply to the amount of wastes in any one of the following:

a) An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal (MTHM) exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM;
b) The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/MTHM and 40,000 MWd/MTHM;
c) Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA);
d) Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years)(for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA); or
e) An amount of transuranic wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years.

(a) Based on Table 1 of Appendix A of 40 CFR 191.
(b) The categories of notes 1(a) through 1(e) are organized according to the waste type and not the radiation emission type. Only TRU wastes are allowed in the WIPP facility, thus only Note 1(e) should be used for identification of the "unit of waste" value. Also, alpha, beta and gamma emitting radionuclides with half-lives greater than 20 years all contribute to the "release limits".
(c) Notes 2 through 6 of Table 1 from Appendix A of 40 CFR191 are not shown here.

As transuranic waste is the waste type in WIPP, the normalized radionuclide release (EPA units), R, is defined by

$$R = \sum_i \left(\frac{Q_i}{f_w L_i} \right) \quad \text{(Equation 1.1)}$$

$$f_w = \frac{\sum W_i}{10^6 Ci} \quad \text{(Equation 1.2)}$$

where Q_i is the cumulative release of radionuclide i to the accessible environment during the 10,000 year period following closure of the repository, L_i is the release limit for radionuclide i given in Table 2, f_w is the "Unit of Waste" defined in Table 2 as the "amount of transuranic wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years" and W_i is the total activity of radionuclide i at closure for alpha-emitting transuranic radionuclides with half-lives greater than 20 years. Accessible environment means (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans and (5) all of the lithosphere that is beyond the controlled area; and the controlled area means (1) surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system and (2) the subsurface underlying such a surface location. To help clarify the intent of 40 CFR 191, the EPA also published 40 CFR 194, *Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations; Final Rule* which gives the following elaboration:

§ 194.34 Results of performance assessments:

(a) The results of performance assessments shall be assembled into "complementary, cumulative distribution functions" (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events.

(b) Probability distributions for uncertain disposal system parameter values used in performance assessments shall be developed and documented in any compliance applications.

(c) Computational techniques, which draw random samples from across the entire range of the probability distributions developed pursuant to paragraph (b) of this section, shall be used in generating CCDFs and shall be documented in any compliance application.

(d) The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability.

(e) Any compliance application shall display the full range of CCDFs generated.

(f) Any compliance application shall provide information which demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of § 191.13 of this chapter.

Based on the requirements in 191.13 and 194.34, the conceptual structure of the WIPP PA consists of (1) a probabilistic characterization of the likelihood of different futures occurring at the WIPP site over the next 10,000 years, (2) a procedure for estimating the radionuclide releases for each future and (3) a probabilistic characterization of the uncertainty in the parameters used in the calculations.

As stated in Section 194.34, the results of the performance assessment are shown as a CCDF indicating the probability of various cumulative release levels. The CCDF of total releases for the latest recertification, the CRA-2004 PABC, is shown in Figure 1. The release limits as stated in Section 191.13 are represented by the dotted line on the right in Figure 1. The solid line in Figure 1 shows the mean probability of the total cumulative releases after addressing the likelihood of different futures occurring at the WIPP site and the uncertainty in the calculation parameters, using computer models that estimate the radionuclide release for each future. The WIPP is in compliance when the total release (solid line) is to the left of the release limits (dotted line). If the mean total release line crosses the release limits line then the WIPP is not in compliance.

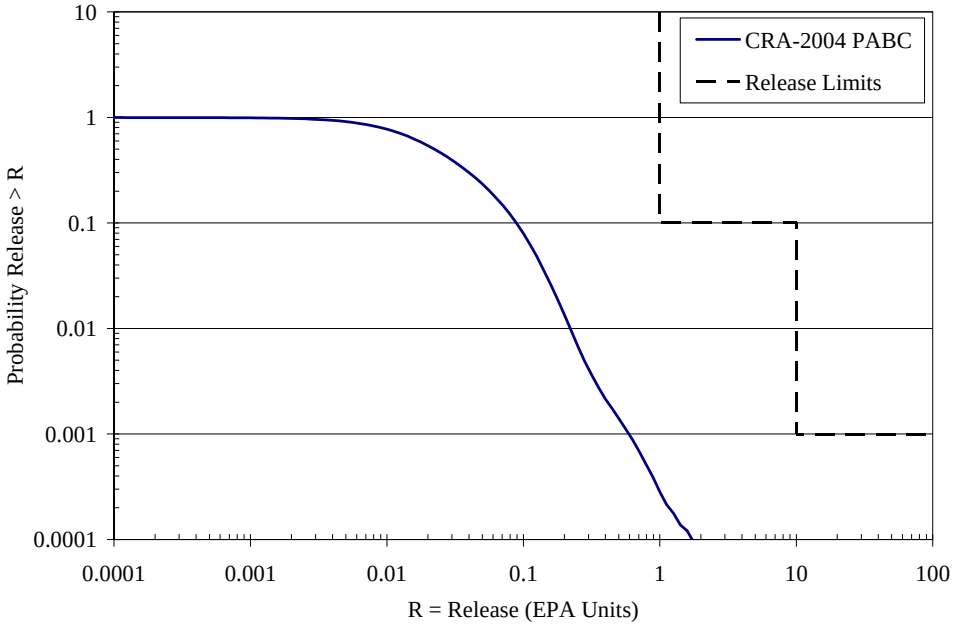

Figure 1. Mean total release CCDF for replicate R1 of the CRA-2004 PABC (Vugrin and Dunagan 2005).

A probabilistic characterization of the likelihood of different futures that could occur at the WIPP site over the next 10,000 years is the outcome of the scenario development process. The scenario development process for the WIPP identified exploratory drilling for natural resources

as the only disruption with sufficient likelihood and consequence (U.S. DOE 1996). In addition, 40 CFR 194 specifies that the occurrence of mining near the site must be included in the analysis. A possible 10,000 year sequence of events at the WIPP is determined by the number of drilling intrusions, the time and location of the intrusions, what was encountered during the intrusion and the time at which mining occurs. For the WIPP PA, 10,000 such possible futures are generated from the probabilities of the intrusion characteristics for use in calculating releases.

The radionuclide release to the accessible environment for the different futures is estimated by computer models of the various release mechanisms. Release mechanisms include direct removal to the surface at the time of a drilling intrusion (i.e. cuttings, cavings, spallings, brine flow) and release subsequent to a drilling intrusion due to brine flow up a borehole (i.e. groundwater transport). Most of the computer models involve the numerical solution of partial differential equations used to represent material deformation, fluid flow and radionuclide transport.

The data development effort for the WIPP provides a probabilistic characterization of the uncertainty in the parameters used in the WIPP PA. Uncertainty accompanies many parameter values used in the computer models. The uncertainty can arise from measurement uncertainty, spatial and temporal variations or lack of data availability. Two techniques are used to address the uncertainty: (1) a bounding value of the parameter is used; or (2) a range and distribution of the parameter is used. For parameters which have a given range and distribution, random sampling is used to obtain the parameter and then the parameter value is associated with a probability. For WIPP PA, 100 different vectors which contain a sampled value of the uncertain parameters are used. The model results for the 100 vectors are evaluated for each of the 10,000 futures (1,000,000 total possibilities). The results are then complied together to generate the final CCDF used to assess the post-closure performance.

1.2 PURPOSE

The GTCC EIS will evaluate the potential environmental impacts from the construction, operation, closure and post-closure performance of a disposal facility for GTCC LLW and DOE GTCC-like waste. This document provides the technical basis for an evaluation of the environmental impacts from post-closure performance of the WIPP facility if the DOE were to decide to dispose of GTCC LLW and DOE GTCC-like waste at WIPP. The document supplies post-closure data identified in the data requirements document (Argonne 2006) including: descriptions of the conditions leading to releases during the performance period, location of the receptors of the releases and amount of release during the performance period at receptor locations.

The post-closure performance data for WIPP has been formulated solely for use in preparing the GTCC EIS. Of necessity, a number of assumptions, which are identified in this report, have been made while developing this post-closure performance data. The result is a post-closure performance data set for the GTCC EIS that adequately represents reasonable expectations for disposal of GTCC LLW and DOE GTCC-like waste at a level of detail commensurate with the data required for EIS evaluations.

1.3 KEY ASSUMPTIONS

For this evaluation, the GTCC LLW is envisioned to be randomly emplaced with the other waste in the WIPP repository, since the receipt of waste is spread over time, as well as be under the same regulatory requirements as currently used in WIPP. The regulatory requirements include the scenarios considered, receptor identity and the current release limits and time frame.

The document, *GTCC LLW Environmental Impact Statement: Pre-closure Assessment Data Package* (SNL 2008b) was used as a data source for the post-closure performance analysis, and so many of the same assumptions made for that data package, carry over into this data package. For example, SNL (2008b) assumed that the disposal of GTCC LLW waste in the WIPP will receive regulatory approval and comply with appropriate Congressional mandates in place at the time of disposal. Currently, the Land Withdrawal Act limits disposal in WIPP to 6.2 million cubic feet of defense-generated transuranic (TRU) waste. Under the current schedule, DOE expects to cease WIPP operations by 2035. However, a baseline change request is being processed that would change the end date for WIPP to 2045 (Johnson 2007). In addition, the baseline change request indicates that the plan is to transition WIPP operations to NNSA which provides a basis for assuming that WIPP operations will be funded beyond 2045 and that GTCC LLW would not bear the entire cost of those operations.

As detailed in SNL (2008a), projected GTCC LLW generation schedules show disposal periods that exceed WIPP's current closure date of 2035 by 30 years (the last of the GTCC LLW activated metal waste is projected to be available for disposal in 2062). Therefore, it is assumed that other waste forms and/or decisions to expand the mission of WIPP occur such that the WIPP facility continues to operate during the GTCC LLW disposal campaign period. This document presents data and information that is specific to the WIPP, and assumes that GTCC LLW and DOE GTCC-like wastes will be disposed using the same (or similar) technologies and methods currently in use at the WIPP for the disposal of defense-related TRU waste.

Currently, the inventory of waste (both CH-TRU and RH-TRU) identified for disposal in WIPP is less than the legislated limits (Lott 2007). However, due to the potential for generation of additional DOE cleanup wastes that may be suitable for disposal at WIPP, this document assumes that additional rooms, beyond the WIPP legislated limits, would need to be constructed to accommodate the disposal of GTCC LLW and DOE GTCC-like waste. It is assumed that RH GTCC LLW and DOE GTCC-like waste would be emplaced using shielded containers using floor space in WIPP. To assess the impact of including the GTCC LLW and DOE GTCC-like waste on post-closure performance, it is assumed that additional disposal rooms are constructed to accommodate the GTCC LLW and DOE GTCC-like waste, as was done for the pre-closure data package (SNL 2008b). The number of rooms needed for each waste stream is shown in Table 3.

Table 3. WIPP Room Space Required for GTCC LLW and DOE GTCC-like Waste Stream Disposal[a]

Waste Stream	Description	Container	Room Space Required
1[b]	GTCC LLW Activated Metal	h-SAMC	4.56
2a	GTCC LLW Non-cesium Sealed Sources	55-gallon drum	0.28
2b	DOE GTCC-like Non-cesium Sealed Sources	55-gallon drum	0.0019
2c	GTCC LLW Cesium Sealed Sources	Irradiator[c]	0.66
2d	DOE GTCC-like Cesium Sealed Sources	Irradiator[c]	0.022
3[b]	DOE GTCC-like Activated Metal	h-SAMC	0.025
4a	GTCC LLW CH Other Waste	55-gallon drum	0.0184
4b	DOE GTCC-like CH Other Waste-- excluding West Valley	55-gallon drum	0.0147
4b	DOE GTCC-like CH Other Waste-- West Valley	SWB	0.31
4c	GTCC LLW RH Other Waste	h-SAMC	0.063
4d	DOE GTCC-like RH Other Waste	h-SAMC	2.67

[a]Calculated in SNL (2008b); [b]SAMC and AMC packages are not suitable for WIPP disposal and will not be considered in this analysis; Activated metals will be disposed in WIPP in h-SAMCs.

Additional assumptions used to prepare the information presented in this report are discussed separately below in each section.

1.4 APPROACH

The approach used in the post-closure performance calculations for the GTCC LLW and DOE GTCC-like waste entails generating the incremental change in post-closure performance for each individual waste stream (and disposal package option) placed separately in the WIPP, as well as the performance with all the GTCC LLW and DOE GTCC-like waste placed in the WIPP. This leads to five cases that were investigated and are denoted 1, 2, 3, 4 and T.

Case 1 includes all of waste stream 1 placed in h-SAMCs.
Case 2 includes all of waste stream 2 placed in 55-gallon drums or irradiators.
Case 3 includes all of waste stream 3 placed in h-SAMCs.
Case 4 includes all of waste stream 4, placed in 55-gallon drums, SWBs and h-SAMCs.
Case T is the sum of Cases 1, 2, 3 and 4.

The conditions leading to the release during the performance period are based on the WIPP scenarios. While the depth of the repository eliminates the applicability of the scenarios indicated in the GTCC EIS Task 3.4 document (SNL 2007), the three performance objectives stated therein: (1) protection of the member of the public (MOP); (2) protection of the inadvertent human intruder (IHI); and (3) long-term site stability; still apply. In the WIPP PA, the protection of the MOP is addressed in the groundwater transport calculations, while the protection of the IHI is dealt with using the WIPP drilling intrusion scenarios. The long-term site stability is also a requirement of the WIPP repository.

The outer edge of the controlled area is used as the location of the MOP in the WIPP PA, while the location of the IHI is directly above the repository, as shown in Figure 2. The WIPP PA receptor locations were used in the post-closure performance calculations for this data package.

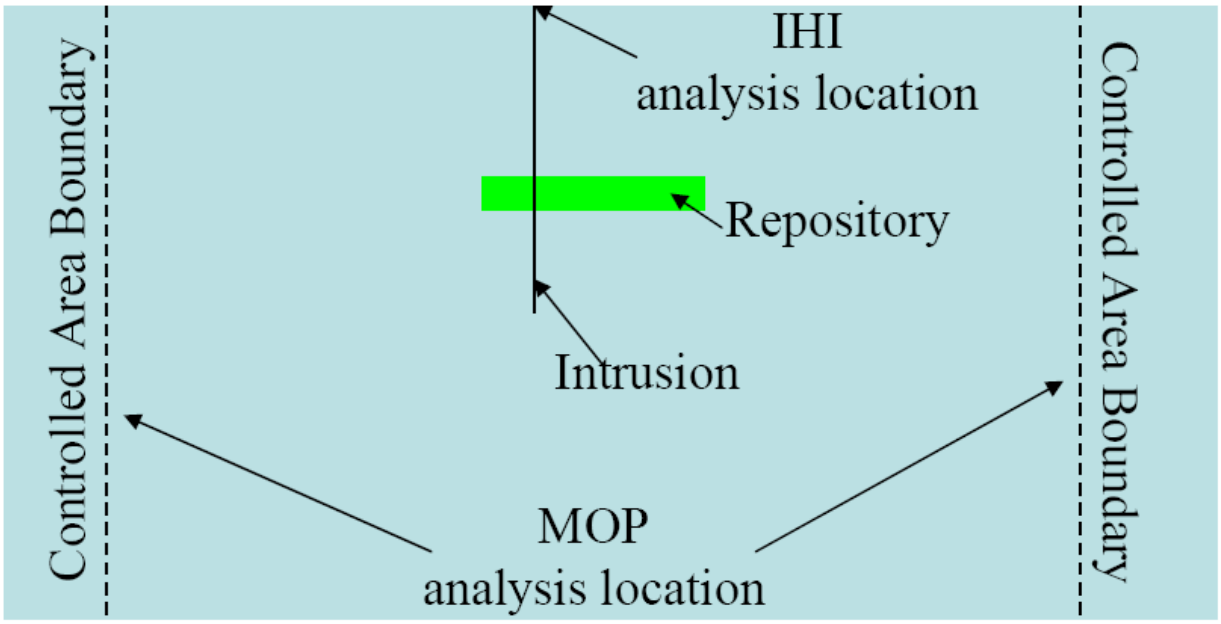

Figure 2. Location for the MOP and IHI used in the post-closure performance analysis.

The amount of release during the performance period at receptor locations is shown using the WIPP methodology. CCDFs that represent the probability of exceeding various levels of the cumulative release caused by all significant processes and events are shown for each GTCC LLW and DOE GTCC-like waste stream, as well as for the total. The release shown is normalized by the "Unit of Waste" defined in Table 2. The CCDF generated by adding the GTCC LLW and DOE GTCC-like waste streams to the WIPP inventory is compared with the baseline CCDF for the WIPP (see Figure 1) to show the incremental change in the post-closure performance.

Each GTCC LLW and DOE GTCC-like waste stream was analyzed to determine the radionuclides that would affect the post-closure performance and need to be included in the calculations (Section 2). Then, any modifications necessary to accommodate the GTCC LLW and DOE GTCC-like waste were made to the input files and the computer models as described in Section 3. The PA was then conducted (Section 4) with the modified files and models. The PA results are shown below in Section 5.

2. WASTE STREAM ANALYSIS

An analysis of the Group 1 inventory was conducted to determine the radionuclides that would affect the post-closure performance calculations. This analysis is repeated for the Group 2 inventory and is documented in Addendum A. The important radionuclides were screened based on the half-life and activity level. In WIPP PA, it is assumed that institutional controls eliminate the possibility of an inadvertent drilling intrusion for the first 100 years after closure. Therefore, radionuclides with half-lives less than 20 years are screened out, as over five half-lives (more including the time between waste placement and facility closure) will significantly reduce the activity. The 40 radionuclides reported for all the GTCC LLW and DOE GTCC-like waste in Group 1 (SNL 2008a and Argonne 2008) are shown in Table 4, along with their respective half-lives (KAPL 2002) and activity for each waste stream at the time of availability. Of the radionuclides listed in Table 4, nine have half-lives that are less than 20 years (^{3}H, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{154}Eu, ^{155}Eu, ^{228}Ra, ^{241}Pu and ^{244}Cm). The ^{3}H, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{154}Eu, ^{155}Eu and ^{228}Ra radionuclides were screened out of the remaining analysis due to their short half-lives, but the ^{241}Pu and ^{244}Cm radionuclides were kept as they have decay products, ^{241}Am and ^{240}Pu (KAPL 2002), that have half-lives longer than 20 years.

Table 4. Radionuclide Activity for Group 1 GTCC LLW and DOE GTCC-like Waste Streams[a]

Radionuclide	Half-life (years)	Activity (Ci)				
		Waste Stream 1	Waste Stream 2	Waste Stream 3	Waste Stream 4	Total
^{3}H	1.23E+01	6.84E+03	-	4.30E-01	1.35E+02	6.97E+03
^{14}C	5.72E+03	2.28E+04	-	6.84E+02	4.06E+02	2.39E+04
^{54}Mn	8.54E-01	4.87E+04	-	2.42E+00	4.60E-02	4.87E+04
^{55}Fe	2.73E+00	3.97E+07	-	5.32E+03	8.43E+02	3.97E+07
^{59}Ni	7.60E+04	1.27E+05	-	3.73E+00	6.26E+02	1.28E+05
^{60}Co	5.27E+00	5.04E+07	-	6.41E+05	5.33E+03	5.10E+07
^{63}Ni	1.00E+02	1.77E+07	-	8.02E+02	4.09E+04	1.77E+07
^{90}Sr	2.88E+01	1.18E+04	-	6.01E-01	7.91E+04	9.09E+04
^{93}Mo	3.50E+03	1.11E+02	-	5.03E-03	7.77E-03	1.11E+02
^{94}Nb	2.00E+04	5.95E+02	-	3.68E+01	3.98E-01	6.32E+02
^{99}Tc	2.13E+05	4.49E+03	-	1.94E-01	6.19E+02	5.11E+03
^{129}I	1.57E+07	1.90E+00	-	8.18E-05	1.03E+02	1.05E+02
^{137}Cs	3.01E+01	1.34E+04	1.80E+06	6.79E-01	3.56E+05	2.17E+06
^{154}Eu	8.59E+00	-	-	-	1.54E+02	1.54E+02
^{155}Eu	4.75E+00	-	-	-	1.40E+01	1.40E+01
^{210}Pb	2.26E+01	-	-	-	3.25E-04	3.25E-04
^{226}Ra	1.60E+03	-	-	-	9.12E+00	9.12E+00
^{228}Ra	5.76E+00	-	-	-	1.13E+00	1.13E+00
^{227}Ac	2.18E+01	-	-	-	9.12E-02	9.12E-02
^{229}Th	7.30E+03	-	-	-	4.98E+00	4.98E+00
^{230}Th	7.54E+04	-	-	-	9.54E-01	9.54E-01
^{232}Th	1.40E+10	-	-	-	1.34E+00	1.34E+00

Table 4. Radionuclide Activity for Group 1 GTCC LLW and DOE GTCC-like Waste Streams[a] (continued)

Radionuclide	Half-life (years)	Activity (Ci)				
		Activity (Ci)	Radionuclide	Half-life (years)	Activity (Ci)	Radionuclide
^{232}U	6.98E+01	-	-	-	5.91E+01	5.91E+01
^{233}U	1.59E+05	-	-	-	8.04E+02	8.04E+02
^{234}U	2.46E+05	-	-	-	9.81E+01	9.81E+01
^{235}U	7.04E+08	-	-	-	1.04E+00	1.04E+00
^{236}U	2.34E+07	-	-	-	3.17E+00	3.17E+00
^{237}Np	2.14E+06	-	-	-	6.09E+00	6.09E+00
^{238}U	4.47E+09	-	-	-	3.38E+00	3.38E+00
^{238}Pu	8.77E+01	8.77E-01	4.24E+04	4.01E-05	4.68E+03	4.71E+04
^{239}Pu	2.41E+04	4.48E+03	3.04E+03	1.94E-01	8.59E+03	1.61E+04
^{240}Pu	6.56E+03	-	2.21E+01	-	6.09E+03	6.11E+03
^{241}Pu	1.44E+01	2.45E+01	-	1.46E-03	7.33E+04	7.34E+04
^{241}Am	4.33E+02	6.35E+01	5.55E+04	2.78E-03	1.30E+04	6.86E+04
^{242}Pu	3.75E+05	-	-	-	2.42E+01	2.42E+01
^{243}Am	7.37E+03	-	3.51E-01	-	4.03E+02	4.03E+02
^{243}Cm	2.91E+01	-	-	-	6.70E+00	6.70E+00
^{244}Cm	1.81E+01	-	5.08E+01	-	8.12E+02	8.63E+02
^{245}Cm	8.50E+03	-	-	-	1.29E+03	1.29E+03
^{246}Cm	4.76E+03	-	-	-	2.09E+02	2.09E+02

[a]All data taken from SNL (2008a) and Argonne (2008).

Using the activity of the 33 remaining radionuclides, normalized by their respective release limits, the radionuclides were screened by determining which ones are necessary to capture the majority of the total activity. Table 5 shows the normalized activity of the 33 remaining radionuclides sorted by the total normalized activity values. The activities were normalized by dividing by their respective release limits to incorporate the fact that radionuclides with higher release limits are less important than radionuclides with lower release limits. For example, ^{63}Ni, ^{241}Am and ^{230}Th have release limits of 1,000, 100 and 10 EPA units (from Table 2), respectively and hence ten times the activity of ^{63}Ni is allowed compared to ^{241}Am and 100 times the activity of ^{63}Ni is allowed compared to ^{230}Th.

Table 5. Normalized Activity for GTCC LLW and DOE GTCC-like Waste Streams

Radionuclide	Release limit (EPA unit)	Normalized Activity (Ci/EPA unit) [a]				
		Waste Stream 1	Waste Stream 2	Waste Stream 3	Waste Stream 4	Total
^{63}Ni	1,000	1.77E+04	-	8.02E-01	4.09E+01	1.77E+04
^{137}Cs	1,000	1.34E+01	1.80E+03	6.79E-04	3.56E+02	2.17E+03
^{241}Am	100	6.35E-01	5.55E+02	2.78E-05	1.30E+02	6.86E+02
^{238}Pu	100	8.77E-03	4.24E+02	4.01E-07	4.68E+01	4.71E+02
^{14}C	100	2.28E+02	-	6.84E+00	4.06E+00	2.39E+02
^{239}Pu	100	4.48E+01	3.04E+01	1.94E-03	8.59E+01	1.61E+02
^{59}Ni	1,000	1.27E+02	-	3.73E-03	6.26E-01	1.28E+02
^{90}Sr	1,000	1.18E+01	-	6.01E-04	7.91E+01	9.09E+01
^{240}Pu	100	-	2.21E-01	-	6.09E+01	6.11E+01
^{241}Pu[b]	-	8.15E-03	-	4.86E-07	2.44E+01	2.44E+01
^{245}Cm	100	-	-	-	1.29E+01	1.29E+01
^{233}U	100	-	-	-	8.04E+00	8.04E+00
^{243}Am	100	-	3.51E-03	-	4.03E+00	4.03E+00
^{246}Cm	100	-	-	-	2.09E+00	2.09E+00
^{129}I	100	1.90E-02	-	8.18E-07	1.03E+00	1.05E+00
^{234}U	100	-	-	-	9.81E-01	9.81E-01
^{94}Nb	1,000	5.95E-01	-	3.68E-02	3.98E-04	6.32E-01
^{232}U	100	-	-	-	5.91E-01	5.91E-01
^{99}Tc	10,000	4.49E-01	-	1.94E-05	6.19E-02	5.11E-01
^{242}Pu	100	-	-	-	2.42E-01	2.42E-01
^{93}Mo	1,000	1.11E-01	-	5.03E-06	7.77E-06	1.11E-01
^{230}Th	10	-	-	-	9.54E-02	9.54E-02
^{243}Cm	100	-	-	-	6.70E-02	6.70E-02
^{237}Np	100	-	-	-	6.09E-02	6.09E-02
^{238}U	100	-	-	-	3.38E-02	3.38E-02
^{236}U	100	-	-	-	3.17E-02	3.17E-02
^{244}Cm[b]	-	-	1.40E-03	-	2.24E-02	2.38E-02
^{232}Th	100	-	-	-	1.34E-02	1.34E-02
^{235}U	100	-	-	-	1.04E-02	1.04E-02
^{226}Ra	1,000	-	-	-	9.12E-03	9.12E-03
^{229}Th	1,000	-	-	-	4.98E-03	4.98E-03
^{227}Ac	1,000	-	-	-	9.12E-05	9.12E-05
^{210}Pb	1,000	-	-	-	3.25E-07	3.25E-07
Total		1.81E+04	2.81E+03	7.69E+00	8.59E+02	2.18E+04

[a]Activity from Table 4 divided by the release limit (Table 2), sorted by the total column. [b]As there are no release limit for radionuclides with half-lives less than 20 years, the normalized release shown is the normalized release of the decay product, derived from the normalized activity of the decay product, which is calculated from the equation $A_1 = A_2 \times \tau_2 \div \tau_1$, (see Section 3.2) where A is the activity and τ is the half-life, and then divided by the decay product release limit.

To determine the radionuclides which are necessary to capture the majority of the total activity, the percent of the total normalized activity for each radionuclide in each waste stream was determined and is shown in Table 6. The radionuclides which did not contribute to at least 0.1% of the total activity were screened out (^{93}Mo, ^{94}Nb, ^{99}Tc, ^{129}I, ^{210}Pb, ^{226}Ra, ^{227}Ac, ^{229}Th, ^{230}Th, ^{232}Th, ^{232}U, ^{235}U, ^{236}U, ^{237}Np, ^{238}U, ^{242}Pu, ^{243}Am, ^{243}Cm, ^{245}Cm and ^{246}Cm). The radionuclides ^{233}U, ^{234}U and ^{244}Cm were retained, as these radionuclides are already incorporated into WIPP PA. After determining the screened in radionuclides from the total normalized activity, the individual waste streams were examined to ensure no significant radionuclides were excluded. As seen in Table 6, the radionuclides that were screened out did not significantly contribute to any of the individual waste stream activities as well, which confirmed the radionuclide selection.

Table 6. Percent of Normalized Activity for GTCC LLW and DOE GTCC-like Waste Streams[a]

Radionuclide	Waste Stream 1	Waste Stream 2	Waste Stream 3	Waste Stream 4	Total
^{63}Ni	81.17%	-	0.00%	0.19%	81.36%
^{137}Cs	0.06%	8.27%	0.00%	1.63%	9.96%
^{241}Am	0.00%	2.55%	0.00%	0.60%	3.14%
^{238}Pu	0.00%	1.94%	0.00%	0.21%	2.16%
^{14}C	1.05%	-	0.03%	0.02%	1.10%
^{239}Pu	0.21%	0.14%	0.00%	0.39%	0.74%
^{59}Ni	0.58%	-	0.00%	0.00%	0.59%
^{90}Sr	0.05%	-	0.00%	0.36%	0.42%
^{240}Pu	-	0.00%	-	0.28%	0.28%
^{241}Pu	0.00%	-	0.00%	0.11%	0.11%
^{245}Cm	-	-	-	0.06%	0.06%
^{233}U	-	-	-	0.04%	0.04%
^{243}Am	-	0.00%	-	0.02%	0.02%
^{246}Cm	-	-	-	0.01%	0.01%
^{129}I	0.00%	-	0.00%	0.00%	0.00%
^{234}U	-	-	-	0.00%	0.00%
^{94}Nb	0.00%	-	0.00%	0.00%	0.00%
^{232}U	-	-	-	0.00%	0.00%
^{99}Tc	0.00%	-	0.00%	0.00%	0.00%
^{242}Pu	-	-	-	0.00%	0.00%
^{93}Mo	0.00%	-	0.00%	0.00%	0.00%
^{230}Th	-	-	-	0.00%	0.00%
^{243}Cm	-	-	-	0.00%	0.00%
^{237}Np	-	-	-	0.00%	0.00%
^{238}U	-	-	-	0.00%	0.00%
^{236}U	-	-	-	0.00%	0.00%
^{244}Cm	-	0.00%	-	0.00%	0.00%
^{232}Th	-	-	-	0.00%	0.00%
^{235}U	-	-	-	0.00%	0.00%
^{226}Ra	-	-	-	0.00%	0.00%
^{229}Th	-	-	-	0.00%	0.00%

Table 6. Percent of Normalized Activity for GTCC LLW and DOE GTCC-like Waste Streams[a] (continued)

Radionuclide	Waste Stream 1	Waste Stream 2	Waste Stream 3	Waste Stream 4	Total
^{227}Ac	-	-	-	0.00%	0.00%
^{210}Pb	-	-	-	0.00%	0.00%
Total	83.13%	12.90%	0.04%	3.94%	100.00%

[a]Normalized activity from Table 5 divided by the total shown in Table 5.

After the screening process, 13 radionuclide remain, ^{14}C, ^{59}Ni, ^{63}Ni, ^{90}Sr, ^{137}Cs, ^{233}U, ^{234}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, and ^{244}Cm, which have longer half-lives and contribute to the majority of the total activity of the GTCC LLW and DOE GTCC-like waste or are already implemented in WIPP PA. Table 7 shows the radionuclide activities, after the screening analyses, which were used for each waste stream in the post-closure performance calculations discussed below.

Table 7. Screened Radionuclide Activity for GTCC LLW and DOE GTCC-like Waste Streams[a]

Radionuclide	Activity (Ci)				
	Waste Stream 1	Waste Stream 2	Waste Stream 3	Waste Stream 4	Total
^{14}C	2.28E+04	-	6.84E+02	4.06E+02	2.39E+04
^{59}Ni	1.27E+05	-	3.73E+00	6.26E+02	1.28E+05
^{63}Ni	1.77E+07	-	8.02E+02	4.09E+04	1.77E+07
^{90}Sr	1.18E+04	-	6.01E-01	7.91E+04	9.09E+04
^{137}Cs	1.34E+04	1.80E+06	6.79E-01	3.56E+05	2.17E+06
^{233}U	-	-	-	8.04E+02	8.04E+02
^{234}U	-	-	-	9.81E+01	9.81E+01
^{238}Pu	8.77E-01	4.24E+04	4.01E-05	4.68E+03	4.71E+04
^{239}Pu	4.48E+03	3.04E+03	1.94E-01	8.59E+03	1.61E+04
^{240}Pu	-	2.21E+01	-	6.09E+03	6.11E+03
^{241}Pu	2.45E+01	-	1.46E-03	7.33E+04	7.34E+04
^{241}Am	6.35E+01	5.55E+04	2.78E-03	1.30E+04	6.86E+04
^{244}Cm	-	5.08E+01	-	8.12E+02	8.63E+02

[a]Data from Table 4.

In the WIPP PA, the CH and RH wastes are tracked separately for some analyses. This is done as waste on the floor is treated differently than waste placed in the walls with regards to release mechanisms. The GTCC LLW and DOE GTCC-like waste was placed with the CH waste for this analysis, as all the container types are containers that are placed on the floor. Thus, the radionuclide activity of the GTCC LLW and DOE GTCC-like waste was tracked with the CH waste even though some of the waste is denoted as RH.

3. INPUT PARAMETERS

Of the many computer codes used in the WIPP PA, the codes PANEL, EPAUNI and CCDFGF are directly affected by a change in the radionuclide activity input parameters. The PANEL code is a radionuclide waste-mobilization model designed specifically to model waste mobilization in the WIPP's wetted repository waste panels, and calculates the normalized release per volume for use in the groundwater transport and direct brine release mechanisms. The EPAUNI code is the computational code that generates the normalized activity per volume as a function of time for use in calculating potential direct solid releases from the repository. The code CCDFGF assembles the release estimates from all other components of the WIPP PA system to generate CCDFs of releases. In order to accommodate the Group 1 GTCC LLW and DOE GTCC-like waste, the input parameters for the PANEL, EPAUNI and CCDFGF codes were modified. A similar input parameter determination is repeated for the Group 2 inventory and is documented in Addendum A.

The "Unit of Waste", f_w, defined in Table 2 as the "amount of transuranic wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years", is one of the input parameters modified to accommodate the GTCC LLW and DOE GTCC-like waste. Of the 13 radionuclides shown in Table 7, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am are used in the calculation of f_w, as they are alpha-emitting transuranic radionuclides with half-lives greater than 20 years. The other nine radionuclides either have half-lives less than 20 years (^{241}Pu and ^{244}Cm) or are not transuranic (^{14}C, ^{59}Ni, ^{63}Ni, ^{90}Sr, ^{137}Cs, ^{233}U and ^{234}U). Using Equation 1.2 and the activities shown in Table 7, the f_w for each waste stream and for the total was calculated and is shown in Table 8. As the post-closure performance calculations were performed by adding the GTCC LLW and DOE GTCC-like waste streams to the WIPP inventory, the combined f_w of each GTCC LLW and DOE GTCC-like waste stream with the WIPP inventory is used in the calculations and is shown in Table 8. The f_w input parameter is used in the PANEL, EPAUNI and CCDFGF codes.

Table 8. The Individual and Combined "Unit of Waste" for GTCC LLW and DOE GTCC-like Waste Streams

	Case 1	Case 2	Case 3	Case 4	Case T
Individual f_w [a]	0.005	0.101	0.000	0.032	0.138
Combined f_w [b]	2.325	2.421	2.320	2.352	2.458

[a]Calculated from Equation 1.2 and the activity from Table 7. [b]Calculated by adding 2.320 (the f_w for the WIPP inventory [Leigh and Trone 2005]) to the individual f_w.

3.1 PANEL

The input parameters that were changed to accommodate the GTCC LLW and DOE GTCC-like waste for the PANEL code calculation are the f_w, as well as the radionuclide activities. Of the 13 radionuclides shown in Table 7, ^{14}C, ^{59}Ni and ^{63}Ni are not currently modeled in the PANEL

code used for WIPP PA. In order to enable the calculations, the PANEL code was modified to incorporate these additional radionuclides. Clayton and Garner (2008) discuss how the PANEL code was modified and validated to include the additional radionuclides.

To run the PANEL code in WIPP PA, four preprocessing codes, GENMESH, MATSET, POSTLHS and ALGEBRACDB, and one post-processing code, SUMMARIZE, must be run. The GENMESH code is run to generate the grid to be used. Next the MATSET code is run to retrieve parameters from the WIPP parameter database, as well as to assign parameter values. The POSTLHS code is then used to modify the parameter values taken from the WIPP parameter database and assign a different value for the 100 vectors based on the parameter distribution. The ALGEBRACDB code is used to calculate any other parameters necessary for the PANEL calculations. The SUMMARIZE code is used to convert the PANEL output to an input used by the CCDFGF code. For the PANEL code execution, run scripts were used to retrieve the appropriate input files and name the corresponding output files. The script, input and output file names and locations for each code execution is shown below in Table 9.

Table 9. PANEL Code, Preprocessor and Post-Processor Script, Input and Output File Names and Locations.

Code/File Type	**File Names**	**Directory**
GENMESH		
Script	GM_PANEL_GTCC.COM	PANEL
Input	GM_PANEL_CRA1BC.INP	PANEL/PNLINP
Output	GM_PANEL_GTCC.CDB	PANEL/GMCDB
Output	GM_PANEL_GTCC.DBG	PANEL/GMCDB
MATSET		
Script	MS_PANEL_GTCC.COM	PANEL
Input	MS_PANEL_GTCC_*c*.INP	PANEL/PNLINP
Input	GM_PANEL_GTCC.CDB	PANEL/GMCDB
Output	MS_PANEL_GTCC_*c*.CDB	PANEL/MSCDB
Output	MS_PANEL_GTCC_*c*.DBG	PANEL/MSCDB
POSTLHS		
Script	LHS3_PANEL_GTCC.COM	PANEL
Input	LHS2_CRA1BC_R1.TRN	PANEL/PNLINP
Input	LHS3_DUMMY.INP	PANEL/PNLINP
Input	MS_PANEL_GTCC_*c*.CDB	PANEL/MSCDB
Output	LHS3_PANEL_GTCC_ *c*_V*vvv*.CDB	PANEL/LHS3CDB
Output	LHS3_PANEL_GTCC_ *c*.DBG	PANEL/LHS3CDB
ALGEBRACDB		
Script	ALG_PANEL_GTCC.COM	PANEL
Input	ALG_PANEL_CRA1BC.INP	PANEL/PNLINP
Input	LHS3_PANEL_GTCC_ *c*_V*vvv*.CDB	PANEL/LHS3CDB
Output	ALG_PANEL_GTCC_ *c*_V*vvv*.CDB	PANEL/ALGCDB
Output	ALG_PANEL_GTCC_ *c*_V*vvv*.DBG	PANEL/ALGCDB

Table 9. PANEL Code, Preprocessor and Post-Processor Script, Input and Output File Names and Locations. (continued)

Code/File Type	File Names	Directory
PANEL		
Script	PANEL_GTCC.COM	PANEL
Input	ALG_PANEL_GTCC_ *c*_V*vvv*.CDB	PANEL/ALGCDB
Output	PANEL_CON_GTCC_ *c*_S*s*_V*vvv*.CDB	PANEL/PNLCDB
Output	PANEL_CON_GTCC_ *c*_S*s*_V*vvv*.DBG	PANEL/PNLCDB
SUMMARIZE		
Script	SUM_GTCC.COM	PANEL
Input	SUM_PANEL_CON_GTCC_*c*_S*s*.INP	PANEL/SUMINP
Input	PANEL_CON_GTCC_ *c*_S*s*_V*vvv*.CDB	PANEL/PNLCDB
Output	SUM_PANEL_CON_GTCC_*c*_S*s*.TBL	PANEL/SUMTBL
Output	GTCC_*c*_S*s*.LOG	PANEL/SUMTBL

1. $c \in \{1, 2, 3, 4, \mathrm{T}\}$
2. $s \in \{1, 2\}$ for each c
3. $vvv \in \{001, 002, ..., 100\}$ for each s

Of the input files listed in Table 9, only the MS_PANEL_GTCC_*c*.INP and SUM_PANEL_CON_GTCC_*c*_S*s*.INP files were modified from the existing baseline, CRA-2004 PABC, PANEL input files. The MS_PANEL_GTCC_*c*.INP files were modified to include the waste stream inventory and the updated f_w. The SUM_PANEL_CON_GTCC_*c*_S*s*.INP files were modified to use the correct file name and location of the PANEL_CON_GTCC_ *c*_S*s*_V*vvv*.CDB files. All other input files used are either input files used in the CRA-2004 PABC or output from a computer code.

3.2 EPAUNI

The input parameters that were changed to accommodate the GTCC LLW and DOE GTCC-like waste for the EPAUNI code calculation are the f_w, as well as the radionuclide activities. Of the 13 radionuclides shown in Table 7, ^{14}C, ^{59}Ni and ^{63}Ni are not currently modeled in the EPAUNI code for WIPP PA. The EPAUNI code models 10 radionuclides as they capture 99% of the activity at the time of closure for the CRA-2004 PABC inventory (Leigh and Fox 2005). In order to enable the calculations, the additional radionuclides were converted to equivalent values of the radionuclides currently implemented in the EPAUNI code. Equivalent radionuclides were chosen based on half-life and calculations using simple and compound decay.

The equation for simple decay (no radioactive daughters) is shown below (Holbert 2006)

$$A(t) = A(0)e^{-\lambda t} \qquad \text{(Equation 3.1)}$$

$$\lambda = \frac{\ln(2)}{\tau} \qquad \text{(Equation 3.2)}$$

where $A(t)$ is the activity at time t, $A(0)$ is the activity at time 0, and τ is the half-life. The activity is the product of the decay constant and the number of atoms (n) (Holbert 2006):

$$A = \lambda n \qquad \text{(Equation 3.3)}$$

Assuming that all of the parent radionuclide decays to a single daughter ($n_1 = n_2$), the relationship between parent and daughter activities can be derived from Equations 3.2 and 3.3 and is given by

$$A_1 = \frac{A_2 \lambda_1}{\lambda_2} = \frac{A_2 \tau_2}{\tau_1} \qquad \text{(Equation 3.4)}$$

where the subscript 1 denotes the parent and subscript 2 denotes the daughter.

The equation for simple decay can be extended to the case in which a radionuclide decays to a daughter product that is also radioactive, and which subsequently decays to a stable end product and is shown below (Holbert 2006).

$$A_2(t) = A_2(0)e^{-\lambda_2 t} + A_1(0)\frac{\lambda_2}{\lambda_2 - \lambda_1}\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right] \qquad \text{(Equation 3.5)}$$

where $A_2(t)$ is the daughter activity at time t, $A_2(0)$ is the daughter activity at time 0, $A_1(0)$ is the parent activity at time 0, and λ_2 and λ_1 are the daughter and parent decay constants, respectively, calculated using Equation 3.2.

Using the Equation 3.1 for the parent decay and adding Equation 3.5, assuming that the initial daughter activity is zero gives an equation for the total activity attributed from the parent

$$A_T(t) = A_1(0)e^{-\lambda_1 t} + A_1(0)\frac{\lambda_2}{\lambda_2 - \lambda_1}\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right] \qquad \text{(Equation 3.6)}$$

where $A_T(t)$ is the total activity of the parent and daughter combined at time t. When the daughter is stable (i.e. $\lambda_2 \approx 0$) then Equation 3.6 reduces to Equation 3.1. Equation 3.1 and 3.6 were used in the determination of equivalent radionuclides for use in the EPAUNI code.

For the ^{14}C radionuclide, ^{240}Pu was chosen as the equivalent radionuclide, as it has a half-life of 6,560 years, which is greater than the ^{14}C's 5,715 year half-life. Furthermore, ^{14}C does not have any radioactive decay products (KAPL 2002) and ^{240}Pu is modeled in EPAUNI without any significant decay products (Leigh and Fox 2005). Using Equation 3.1, the decay at 10,000 years is calculated as 29.7% and 34.8% of the original activity using the ^{14}C and ^{240}Pu half-lives, respectively. Therefore, the activity of the ^{14}C is captured and overestimated, with a maximum overestimation of 5.1% of the initial activity using ^{240}Pu as the equivalent radionuclide. Both ^{14}C

and ^{240}Pu have release limits of 100 EPA units and so no adjustment to the activity was necessary to account for differing release limits.

For the ^{59}Ni radionuclide, ^{234}U was chosen as the equivalent radionuclide, as it has a half-life of 246,000 years, which is greater than the ^{59}Ni's 76,000 year half-life. Furthermore, ^{59}Ni does not have any radioactive decay products (KAPL 2002) and ^{234}U is modeled in EPAUNI without any significant decay products (Leigh and Fox 2005). Using Equation 3.1, the decay at 10,000 years is calculated as 91.3% and 97.2% of the original activity using the ^{59}Ni and ^{234}U half-lives, respectively. Therefore, the activity of the ^{59}Ni is captured and overestimated, with a maximum overestimation of 5.9% of the initial activity using ^{234}U as the equivalent radionuclide. The ^{59}Ni has a release limit of 1,000 EPA units and ^{234}U has release limits of 100 EPA units, so the activity of the ^{59}Ni was divided by 10 when using the ^{234}U as the equivalent radionuclide to account for differing release limits.

For the ^{63}Ni radionuclide, ^{238}Pu was chosen as the equivalent radionuclide, even though it has a half-life of 87.7 years, which is less than the ^{63}Ni's 100 year half-life. The ^{63}Ni does not have any radioactive decay products (KAPL 2002) and ^{238}Pu is modeled in EPAUNI to decay to ^{234}U (Leigh and Fox 2005). The time history using Equation 3.1 for the ^{63}Ni activity and Equation 3.6 for the ^{238}Pu activity assuming equal initial activities is shown below in Figure 3. As seen in Figure 3, without scaling the ^{238}Pu activity, underestimation of the activity results between 0 and 1,100 years.

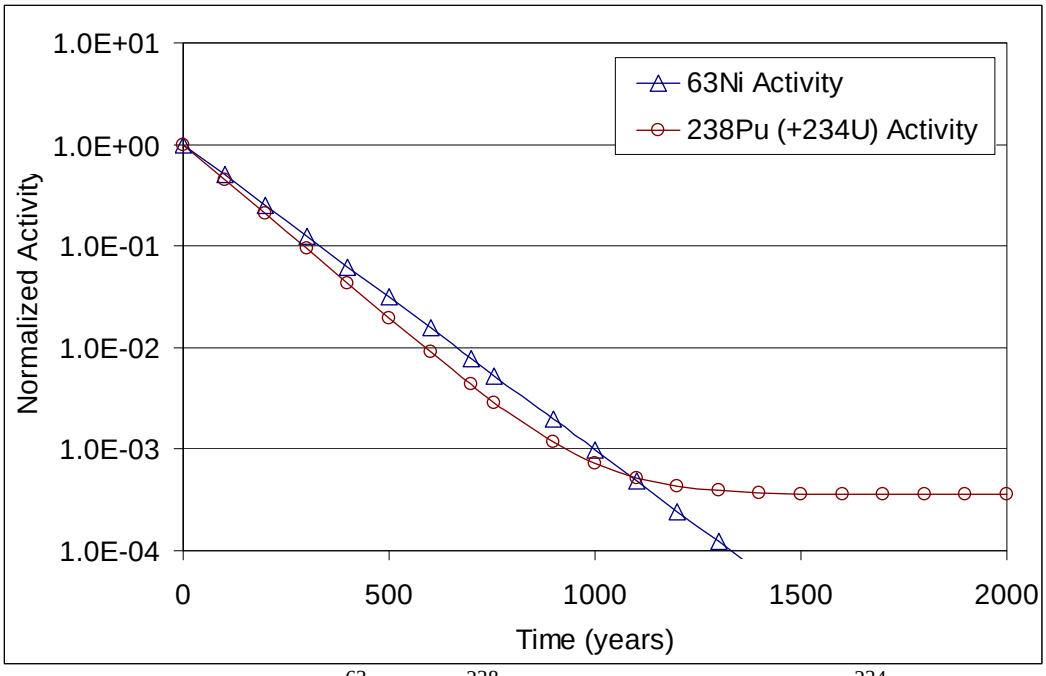

Figure 3. Normalized activity of ^{63}Ni and ^{238}Pu (and the decay product ^{234}U) versus time with equal initial activities.

To correct this underestimation, the equivalent ^{238}Pu activity was scaled such that the activity is greater than or equal to the ^{63}Ni activity at all times. A scaling factor of 1.83 was found to satisfy this requirement. Using Equation 3.1 for the ^{63}Ni activity and Equation 3.6 for the ^{238}Pu

activity incorporating the 1.83 scaling factor, the time history of the activity can be calculated and is shown below in Figure 4. As seen in Figure 3, the activity of the ^{63}Ni is captured using ^{238}Pu as the equivalent radionuclide when including the 1.83 scaling factor. The ^{63}Ni has a release limit of 1,000 EPA units and ^{238}Pu has release limits of 100 EPA units, so the activity of the ^{63}Ni was divided by 10, after scaling by the 1.83 factor, when using the ^{238}Pu as the equivalent radionuclide to account for differing release limits.

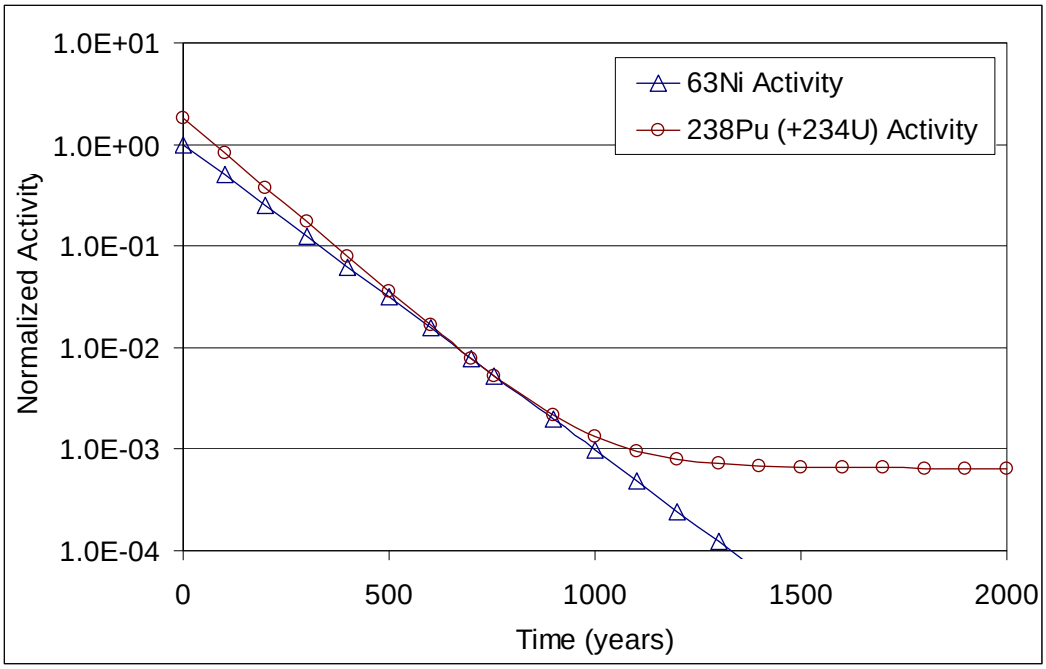

Figure 4. Normalized activity of ^{63}Ni and ^{238}Pu (and the decay product ^{234}U) versus time with scaled initial activities.

Using the equivalent radionuclides discussed above, input values for the activities of the 10 radionuclides modeled in the EPAUNI can be derived and are shown in Table 10. The activities shown in Table 10 were used to modify the EPAUNI input files.

Table 10. Equivalent Radionuclide Activity (Ci) Used in EPAUNI for Each Group 1 Case[a]

Equivalent Radionuclide	Case 1	Case 2	Case 3	Case 4	Case T
^{90}Sr	1.18E+04	-	6.01E-01	7.91E+04	9.09E+04
^{137}Cs	1.34E+04	1.80E+06	6.79E-01	3.56E+05	2.17E+06
^{233}U	-	-	-	8.04E+02	8.04E+02
^{234}U[b]	1.27E+04	-	3.73E-01	1.61E+02	1.29E+04
^{238}Pu[c]	3.24E+06	4.24E+04	1.47E+02	1.22E+04	3.29E+06
^{239}Pu	4.48E+03	3.04E+03	1.94E-01	8.59E+03	1.61E+04
^{240}Pu[d]	2.28E+04	2.21E+01	6.84E+02	6.49E+03	3.00E+04
^{241}Pu	2.45E+01	-	1.46E-03	7.33E+04	7.34E+04
^{241}Am	6.35E+01	5.55E+04	2.78E-03	1.30E+04	6.86E+04
^{244}Cm	-	5.08E+01	-	8.12E+02	8.63E+02

[a]Based on data in Table 7. [b]Sum of ^{234}U and ^{59}Ni/10 activities. [c]Sum of ^{238}Pu and 1.83/10 × ^{63}Ni activities. [d]Sum of ^{240}Pu and ^{14}C activities.

For the EPAUNI code execution, no preprocessor or post-processor codes are needed. Run scripts were used to retrieve the appropriate input files and name the corresponding output files. The script, input and output file names and locations for each code execution is shown below in Table 11.

Table 11. EPAUNI Code Script, Input and Output File Names and Locations.

Code/File Type	File Names	Directory
EPAUNI		
Script	EPU_GTCC.COM	EPAUNI
Input	EPU_GTCC_*c*_CH.INP	EPAUNI/EPUINP
Input	EPU_GTCC_*c*_CH_MISC.INP	EPAUNI/EPUINP
Output	EPU_GTCC_*c*_CH.DAT	EPAUNI/EPUDAT
Output	EPU_GTCC_*c*_CH.OUT	EPAUNI/EPUOUT
Output	EPU_GTCC_*c*_CH.OUT2	EPAUNI/EPUOUT
Output	EPU_GTCC_*c*_CH.DIA	EPAUNI/EPUOUT
Output	EPU_GTCC_*c*_CH_ACTIVITY.DIA	EPAUNI/EPUOUT

1. $c \in \{1, 2, 3, 4, \mathrm{T}\}$

The EPU_GTCC_*c*_CH.INP files were modified to add the activity of the GTCC LLW and DOE GTCC-like waste for each case and the EPU_GTCC_*c*_CH_MISC.INP files were modified to include the updated f_w.

3.3 CCDFGF

The input parameters that were changed to accommodate the GTCC LLW and DOE GTCC-like waste for the CCDFGF code calculation are the f_w, the CH area, the repository volume and the repository fraction occupied by waste. The CH area and repository volume parameters were modified based on the number of rooms required for each case as shown in Table 3. The repository fraction occupied by waste parameter was modified based on the calculated repository volume and the Group 1 GTCC LLW and DOE GTCC-like waste volumes shown in Table 1.

The ratio of the CH area to the total area is used to determine the probability that an intrusion intersects CH waste. The CH area parameter for the WIPP PA is set at 1.115E+05 m^2. The CH area parameter was modified to account for the additional rooms required to accommodate the GTCC LLW and DOE GTCC-like waste by multiplying the WIPP PA CH area parameter by the fractional increase in rooms.

The number of CH rooms required for each case was determined by calculating the number of stacks required for each waste stream/container combination and dividing by 542 stacks per room (SNL 2008b). As there are 3,636 stacks in a typical waste panel and 10 panels in the repository (SNL 2008b), this gives 66.59 average rooms in the repository. The CH area parameter was then scaled by one plus the ratio of the required GTCC LLW CH rooms to the WIPP rooms. The scaled CH area parameters for each case are shown in Table 12.

The repository volume parameter (4.384E+05 m^3) used in the WIPP PA represents the total volume of the rooms in the repository. Therefore, the repository volume parameter was scaled using the required GTCC LLW CH rooms, similar to the CH area scaling. The scaled repository volume parameters for each case are shown in Table 12.

Table 12. The CH Area and Repository Volume Parameters Used in CCDFGF Calculations

Case	Rooms Needed[a]	CH area (m^2)[b]	Repository Volume (m^3)[c]
Case 1	4.56	1.191E+05	4.684E+05
Case 2	0.96	1.131E+05	4.448E+05
Case 3	0.025	1.115E+05	4.386E+05
Case 4	3.08	1.167E+05	4.587E+05
Case T	8.63	1.259E+05	4.952E+05

[a]From Table 3. [b]Calculated as 1.115E+05 × (1 + CH Rooms Needed ÷ 66.59). [c]Calculated as 4.384E+05 × (1 + CH Rooms Needed ÷ 66.59).

The repository fraction occupied by waste parameter was modified based on the calculated repository volume parameter and the GTCC LLW and DOE GTCC-like waste volumes shown in Table 1. This parameter was modified to account for the difference in the capacity and rooms space required for the containers used for the GTCC LLW and DOE GTCC-like waste. Volume of waste per package (SNL 2007a) and the number of packages per stack (SNL 2007b) is different between the h-SAMCs, CIS-US blood irradiators, SWBs and 55-gallon drums. To account for these differences, the repository fraction occupied by waste parameter was modified. The WIPP PA repository fraction occupied by waste parameter is calculated at 0.385. The scaled repository fraction occupied by waste parameter was modified by dividing the total waste volume (WIPP plus GTCC) for each case and dividing by the scaled repository volume for each case. The scaled repository fraction occupied by waste parameters are shown in Table 13.

Table 13. The Repository Fraction Occupied by Waste Parameters Used in CCDFGF Calculations

Case	CH Waste Volume (m^3)[a]	Repository Fraction Occupied by Waste[b]
Case 1	882	0.362
Case 2	1,704.5	0.383
Case 3	12.8	0.385
Case 4	2,519.1	0.373
Case T	5,118.4	0.351

[a]From SNL (2008a) and Argonne (2008). [b]Calculated as (4.384E+05 m^3 × 0.385 + GTCC CH waste volume) / scaled repository volume (Table 12); "Repository Fraction Occupied by Waste" is defined as the waste volume divided by the repository volume.

To run the CCDFGF code in WIPP PA, four preprocessing codes, GENMESH, MATSET, POSTLHS and PRECCDFGF must be run. The GENMESH code is run to generate the grid to be used. Next the MATSET code is run to retrieve parameters from the WIPP parameter database, as well as to assign parameter values. The POSTLHS code is then used to modify the

parameter values taken from the WIPP parameter database and assign a different value for the 100 vectors based on the parameter distribution. The PRECCDFGF code is used to combine the output from all of the other codes into a single input used by the CCDFGF code. For the CCDFGF code execution, run scripts were used to retrieve the appropriate input files and name the corresponding output files. The script, input and output file names and locations for each code execution is shown below in Table 14.

Table 14. CCDFGF Code and Preprocessor Script, Input and Output File Names and Locations.

Code/File Type	**File Names**	**Directory**
GENMESH		
Script	GM_CCGF_GTCC.COM	CCDFGF
Input	GM_CCGF_CRA1BC.INP	CCDFGF/CCGFINP
Output	GM_CCGF_GTCC.CDB	CCDFGF/GMCDB
Output	GM_CCGF_GTCC.DBG	CCDFGF/GMCDB
MATSET		
Script	MS_CCGF_GTCC.COM	CCDFGF
Input	MS_CCGF_GTCC_*c*.INP	CCDFGF/CCGFINP
Input	GM_CCGF_GTCC.CDB	CCDFGF/GMCDB
Output	MS_CCGF_GTCC_*c*.CDB	CCDFGF/MSCDB
Output	MS_CCGF_GTCC_*c*.DBG	CCDFGF/MSCDB
POSTLHS		
Script	LHS3_CCGF_GTCC.COM	CCDFGF
Input	LHS2_CRA1BC_R1.TRN	CCDFGF/CCGFINP
Input	LHS3_DUMMY.INP	CCDFGF/CCGFINP
Input	MS_CCGF_GTCC_*c*.CDB	CCDFGF/MSCDB
Output	LHS3_CCGF_GTCC_ *c*_V*vvv*.CDB	CCDFGF/LHS3CDB
Output	LHS3_CCGF_GTCC_ *c*.DBG	CCDFGF/LHS3CDB
PRECCDFGF		
Script	PRECCDFGF_GTCC.COM	CCDFGF
Input	MS_CCGF_GTCC_*c*.CDB	CCDFGF/MSCDB
Input	LHS3_CCGF_GTCC_ *c*_V*vvv*.CDB	CCDFGF/LHS3CDB
Input	SUM_PANEL_CON_GTCC_*c*_S*s*.TBL	PANEL/SUMTBL
Input	EPU_GTCC_*c*_CH.DAT	EPAUNI/EPUDAT
Input	EPU_CRA1BC_RH.DAT	CCDFGF/CRA1BCFILES
Input	INTRUSIONTIMES.IN	CCDFGF/CRA1BCFILES
Input	CUSP_CRA1BC_R1.TBL	CCDFGF/CRA1BCFILES
Input	SUM_DBR_CRA1BC_R1_S*s*_T*ttttt_d*.TBL	CCDFGF/CRA1BCFILES
Input	SUM_NUT_CRA1BC_R1_S1.TBL	CCDFGF/CRA1BCFILES
Input	SUM_NUT_CRA1BC_R1_S*s*_T*ttttt*.TBL	CCDFGF/CRA1BCFILES
Input	SUM_PANEL_INT_CRA1BC_R1_S6_T*ttttt*.TBL	CCDFGF/CRA1BCFILES
Input	SUM_PANEL_ST_CRA1BC_R1_S*s*.TBL	CCDFGF/CRA1BCFILES
Input	SUM_ST2D_CRA1BC_R1_M*m*.TBL	CCDFGF/CRA1BCFILES
Output	RELTAB_GTCC_*c*.DAT	CCDFGF/CCGFINP

Table 14. CCDFGF Code and Preprocessor Script, Input and Output File Names and Locations. (continued)

Code/File Type	File Names	Directory
CCDFGF		
Script	CCGF_GTCC.COM	CCDFGF
Input	CCGF_CRA1BC_CONTROL_R1.INP	CCDFGF/CCGFINP
Input	RELTAB_GTCC_*c*.DAT	CCDFGF/CCGFINP
Output	CCGF_GTCC_*c*.OUT	CCDFGF/CCGFOUT
Output	CCGF_GTCC_*c*.PRT	CCDFGF/CCGFOUT

1. $c \in \{1, 2, 3, 4, \text{T}\}$
2. $vvv \in \{001, 002, ..., 100\}$ for each c
3. $s \in \begin{cases} \{1, 2, 3, 4, 5\} \text{ for SUM\_DBR} \\ \{2, 3, 4, 5\} \text{ for SUM\_NUT} \\ \{1, 2\} \text{ for SUM\_PANEL\_ST} \\ \{1, 2\} \text{ for SUM\_PANEL\_CON for each } c \end{cases}$
4. $ttttt \in \begin{cases} \{00100, 00350, 01000, 03000, 05000, 10000\} \text{ for S1 for SUM\_DBR} \\ \{00550, 07500, 02000, 04000, 10000\} \text{ for S2, S4 for SUM\_DBR} \\ \{01200, 01400, 03000, 05000, 10000\} \text{ for S3, S5 for SUM\_DBR} \\ \{00100, 00350\} \text{ for S2, S4 for SUM\_NUT} \\ \{01000, 03000, 05000, 07000, 09000\} \text{ for S3, S5 for SUM\_NUT} \\ \{00100, 00350, 01000, 02000, 04000, 06000, 09000\} \text{ for SUM\_PANEL\_INT} \end{cases}$
5. $d \in \{\text{L, M, U}\}$ for each $ttttt$
6. $m \in \{\text{F, P}\}$

Of the input files listed in Table 14, only the MS_CCGF_GTCC_*c*.INP files were modified to include the updated f_w, repository volume, CH effective area and repository fraction occupied by waste. All other input files used are either input files used in the CRA-2004 PABC or output from the computer codes.

4. POST-CLOSURE PERFORMANCE RESULTS

The post-closure performance results show that including the Group 1 GTCC LLW and DOE GTCC-like waste in the WIPP repository will satisfy the three performance objectives stated in the GTCC EIS Task 3.4 document (SNL 2007). The WIPP repository has no significant MOP groundwater releases and adding the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP repository does not cause a significant MOP groundwater release. The incremental increases in the normalized releases to the IHI from adding the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP repository are not substantial enough to jeopardize the WIPP repository compliance with the release limits. The WIPP repository has long-term stability and adding the GTCC LLW and DOE GTCC-like waste does not adversely affect the long-term stability. More details of the post-closure performance results are discussed below. The post-closure performance results for the Group 2 inventory is documented in Addendum A.

4.1 UNDISTURBED RESULTS (MOP)

For WIPP PA, Salado transport calculations are performed for the undisturbed scenario to determine the concentration of radionuclides at receptor locations. The Salado transport calculations for the CRA-2004 PABC show negligible radionuclide concentrations at receptor locations, which are most likely due to numerical dispersion as a result of the finite-difference solution (Lowry 2005) and should instead, be zero. As the addition of the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP inventory would increase the total radionuclide concentration by at most one order of magnitude (see Section 4.2.1), the undisturbed result from the CRA-2004 PABC Salado transport calculations is still applicable. Therefore, there are no releases to the MOP at the receptor locations with the addition of the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP repository.

4.2 DISTURBED RESULTS (IHI)

4.2.1 PANEL results

The PANEL code is a radionuclide waste-mobilization model designed specifically to model waste mobilization in the WIPP's wetted repository waste panels, and calculates the normalized release per volume for use in the groundwater transport and direct brine release mechanisms. The output from the PANEL code is the normalized release of radionuclide per volume of brine. The normalized release concentrations that resulted from the PANEL code with the addition of the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP inventory are discussed below.

As the concentrations are used in the groundwater transport and direct brine release mechanism modeling, an increase in the concentration will result in an increase in the cumulative release. The normalized concentrations that resulted from the addition of waste stream 1 showed a significant increase compared with the baseline WIPP PA, while waste streams 2, 3 and 4 showed little to no increase. The details of the PANEL results for the individual cases are given below.

4.2.1.1 Case 1 (GTCC LLW Activated Metal)

Adding Group 1 GTCC LLW and DOE GTCC-like waste stream 1 to the WIPP inventory increased the total radionuclide concentration significantly. Figure 5 shows the total concentration as a function of time, comparing the results for Case 1 and the modified PANEL code with the PANEL version 4.03 results using the WIPP baseline inventory (Garner and Leigh 2005). Many radionuclides use a distribution for the solubility limit to capture the uncertainty, and so 100 sets with different solubility limits for those radionuclides are used, while for other radionuclides, a single solubility is used and so the same value is used in each of the 100 sets. The total concentration is a sum of all the radionuclide concentrations and so will generally decrease with time. As seen in Figure 5, the total concentration for the Case 1 is always higher than the WIPP baseline in all of the 100 sets.

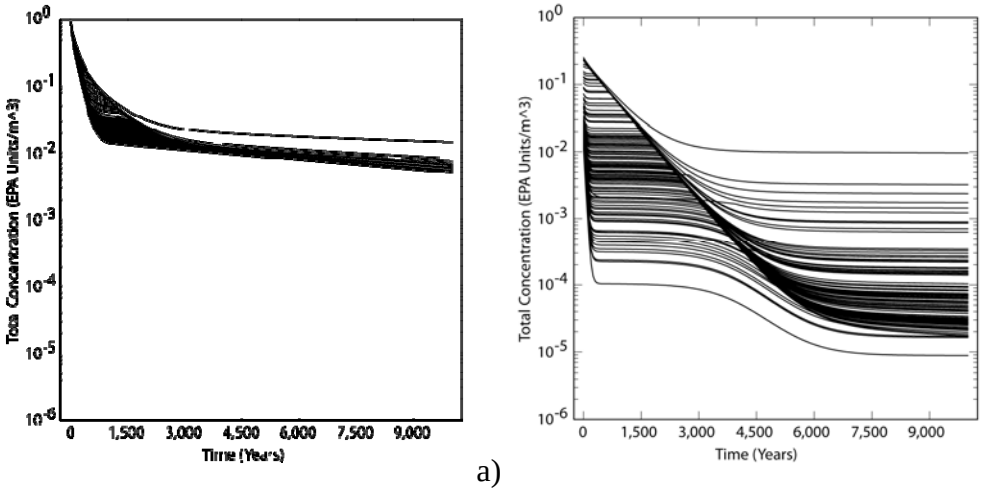

Figure 5. Total radionuclide concentration using the a) modified PANEL code with Case 1 inventory and b) PANEL version 4.03 with the WIPP baseline inventory (Garner and Leigh 2005).

The increase in the total concentration is mainly due to the ^{14}C, ^{59}Ni and ^{63}Ni in waste stream 1. Figure 6 shows the normalized concentration of ^{14}C, ^{59}Ni and ^{63}Ni as a function of time for Case 1. A single solubility value is used for these radionuclides which is sufficiently high, such that the concentration is limited by the inventory and not the solubility limit. As seen in Figure 6, the concentrations of the ^{14}C, ^{59}Ni are of the order of 1.E-03 EPA Units/m^3, while the concentration of the ^{63}Ni starts out at ~6.E-01 EPA Units/m^3, but then sharply decreases. The effect from the ^{14}C, ^{59}Ni and ^{63}Ni on the total concentration for Case 1 can be seen in the minimum of the 100 sets, as it is dominated by the ^{63}Ni concentration for times before ~1,000 years and by the sum of the ^{14}C and ^{59}Ni concentrations for times after ~1,000 years (see Figure 5).

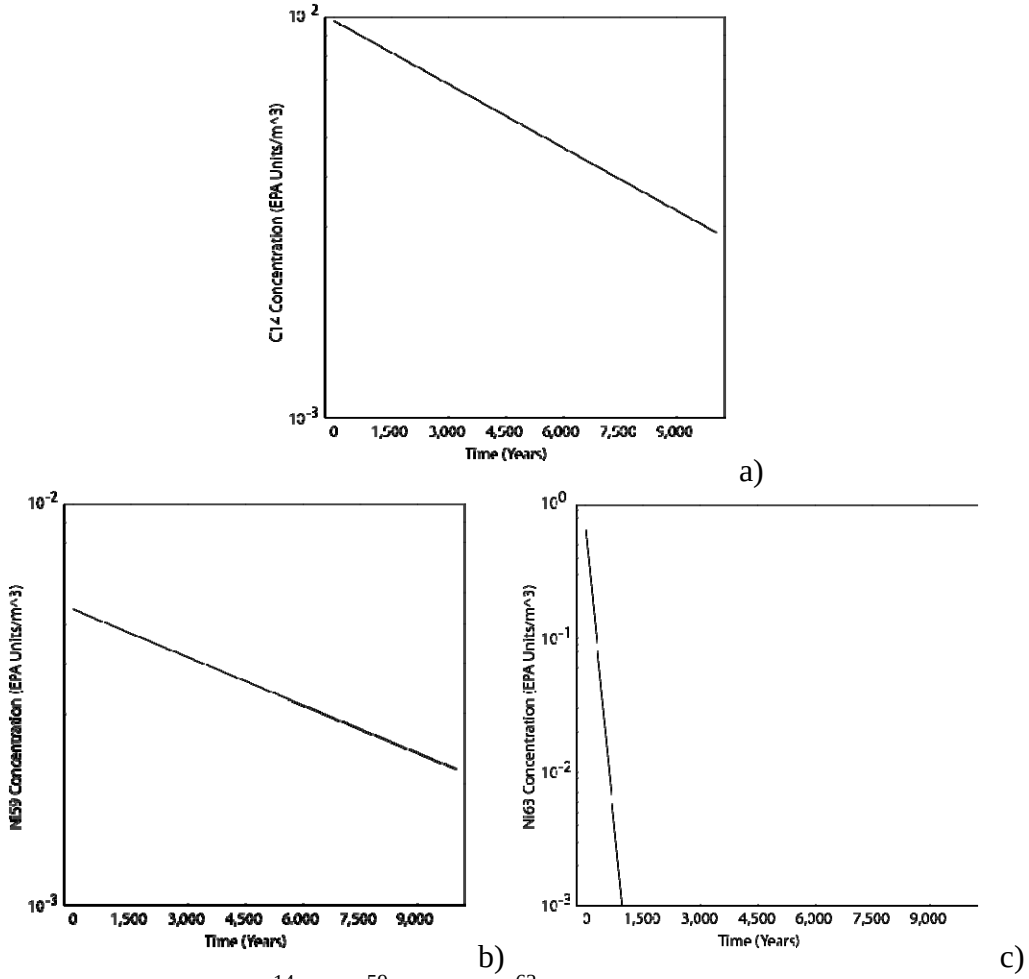

Figure 6. Concentration of a) ^{14}C, b) ^{59}Ni and c) ^{63}Ni using the modified PANEL code with Case 1 inventory.

4.2.1.2 Case 2 (GTCC LLW and DOE GTCC-like Sealed Sources)

Adding Group 1 GTCC LLW and DOE GTCC-like waste stream 2 to the WIPP inventory did not significantly increase the total radionuclide concentration. Figure 7 shows the total concentration as a function of time, comparing the results for Case 2 and the modified PANEL code with the PANEL version 4.03 results using the WIPP baseline inventory (Garner and Leigh 2005). Many radionuclides use a distribution for the solubility limit to capture the uncertainty, and so 100 sets with different solubility limits for those radionuclides are used, while for other radionuclides, a single solubility is used and so the same value is used in each of the 100 sets. The total concentration is a sum of all the radionuclide concentrations and so will generally decrease with time. As seen in Figure 7, the total concentration for the Case 2 is very similar to the WIPP baseline.

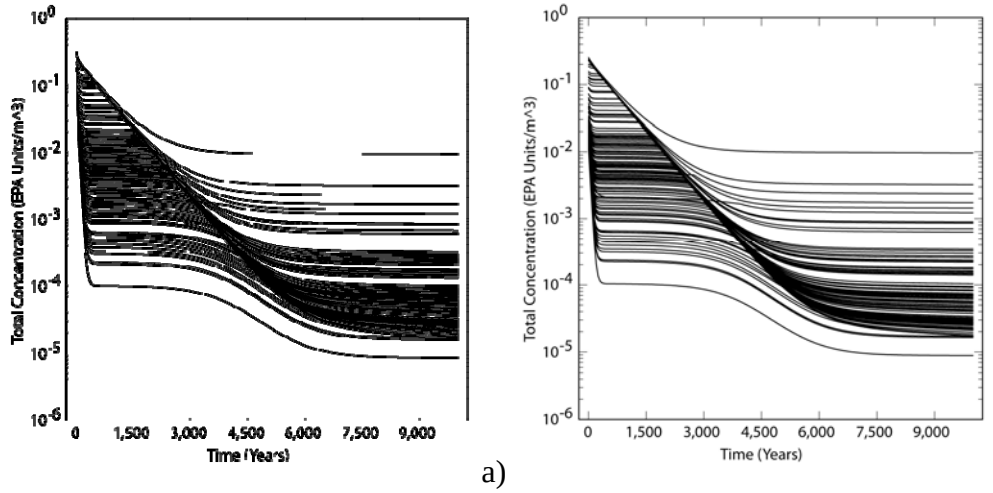

Figure 7. Total radionuclide concentration using the a) modified PANEL code with Case 2 inventory and b) PANEL version 4.03 with the WIPP baseline inventory (Garner and Leigh 2005).

As seen in Table 6, waste stream 2 is dominated by ^{137}Cs. Figure 8 shows the normalized concentration of ^{137}Cs as a function of time for Case 2 compared with the WIPP baseline inventory. A single solubility value is used in WIPP PA for this radionuclide which is sufficiently high, such that the concentration is limited by the inventory and not the solubility limit. As seen in Figure 8, while the addition of waste stream 2 increased the amount of ^{137}Cs by an order of magnitude, since the ^{137}Cs has a relatively short half-life (30.1 years) the change is not significant when compared with 10,000 years (see Figure 7).

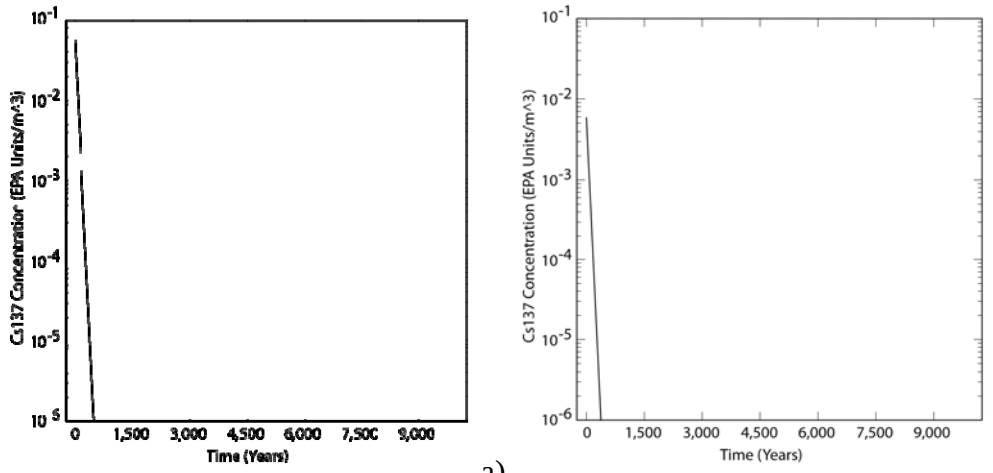

Figure 8. Concentration of ^{137}Cs using the a) modified PANEL code with Case 2 inventory and b) PANEL version 4.03 with the WIPP baseline inventory (Garner and Leigh 2005).

4.2.1.3 Case 3 (DOE GTCC-like Activated Metal)

Adding Group 1 GTCC LLW and DOE GTCC-like waste stream 3 to the WIPP inventory slightly increased the total radionuclide concentration. Figure 9 shows the total concentration as

a function of time, comparing the results for Case 3 and the modified PANEL code with the PANEL version 4.03 results using the WIPP baseline inventory (Garner and Leigh 2005). Many radionuclides use a distribution for the solubility limit to capture the uncertainty, and so 100 sets with different solubility limits for those radionuclides are used, while for other radionuclides, a single solubility is used and so the same value is used in each of the 100 sets. The total concentration is a sum of all the radionuclide concentrations and so will generally decrease with time. As seen in Figure 9, the total concentration for the Case 3 is higher for the sets with relatively low concentrations (10^{-4} EPA Units/m^3), while the increase is insignificant for the higher concentration sets when compared to the WIPP baseline.

The increase in the total concentration is mainly due to the ^{14}C in waste stream 3. Figure 10 shows the normalized concentration of ^{14}C, ^{59}Ni and ^{63}Ni as a function of time for Case 3. A single solubility value is used for these radionuclides which is sufficiently high, such that the concentration is limited by the inventory and not the solubility limit. As seen in Figure 10, the concentration of the ^{14}C ranges from ~1.E-04 to ~3.E-04 EPA Units/m^3, while the ^{59}Ni and ^{63}Ni concentrations are much lower. The effect from the ^{14}C on the total concentration for Case 3 can be seen in the minimum of the 100 sets, as it is dominated by the ^{14}C concentration (see Figure 9).

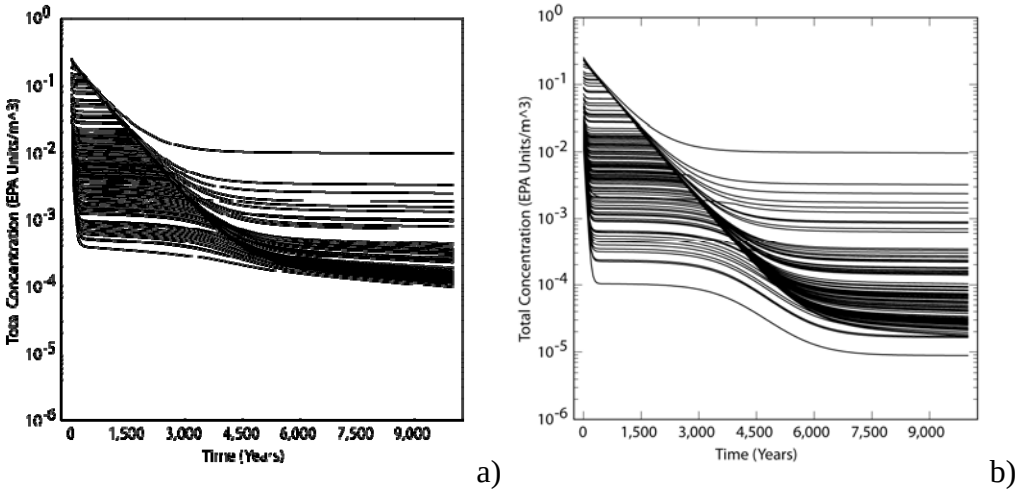

Figure 9. Total radionuclide concentration using the a) modified PANEL code with the Case 3 inventory and b) PANEL version 4.03 with the WIPP baseline inventory (Garner and Leigh 2005).

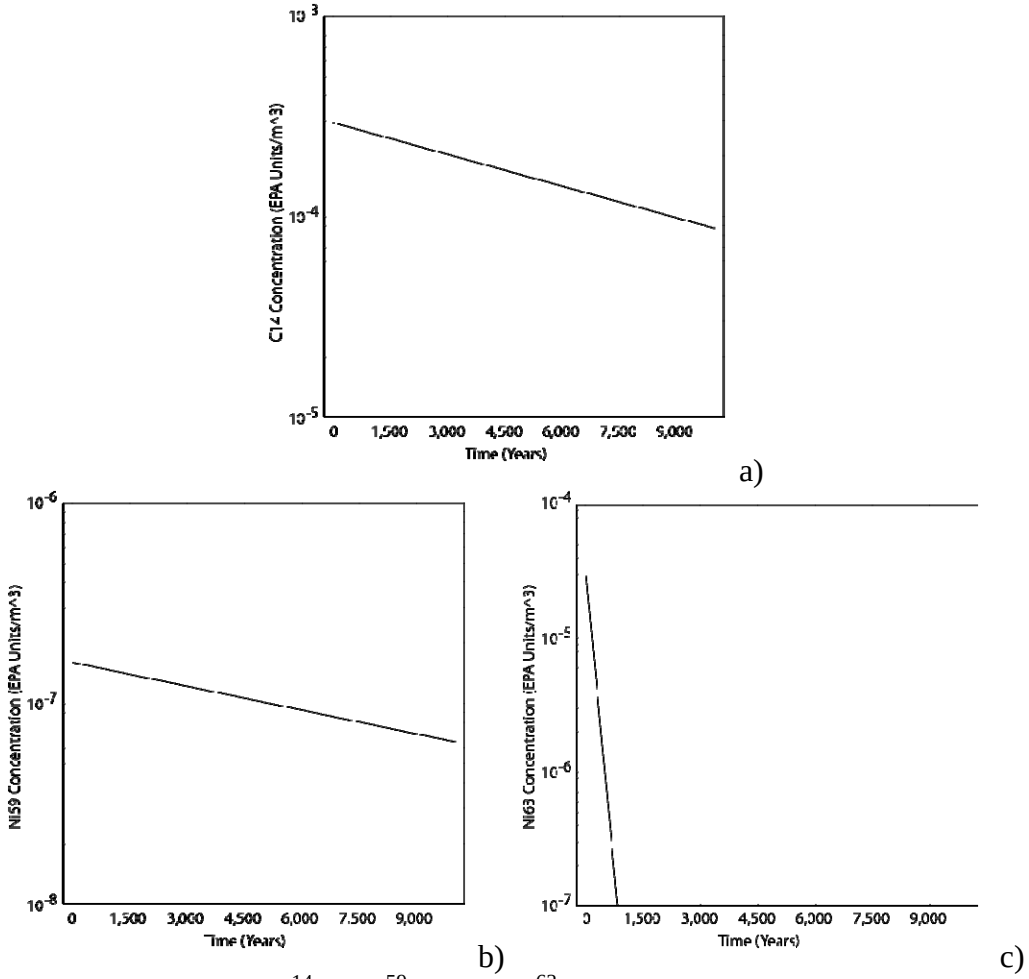

Figure 10. Concentration of a) ^{14}C, b) ^{59}Ni and c) ^{63}Ni using the modified PANEL code with the Case 3 inventory.

4.2.1.4 Case 4 (GTCC LLW and DOE GTCC-like Other Waste)

Adding Group 1 GTCC LLW and DOE GTCC-like waste stream 4 to the WIPP inventory slightly increased the total radionuclide concentration. Figure 11 shows the total concentration as a function of time, comparing the results for Case 4 and the modified PANEL code with the PANEL version 4.03 results using the WIPP baseline inventory (Garner and Leigh 2005). Many radionuclides use a distribution for the solubility limit to capture the uncertainty, and so 100 sets with different solubility limits for those radionuclides are used, while for other radionuclides, a single solubility is used and so the same value is used in each of the 100 sets. The total concentration is a sum of all the radionuclide concentrations and so will generally decrease with time. As seen in Figure 11, the total concentration for the Case 4 is slightly increased compared to the WIPP baseline.

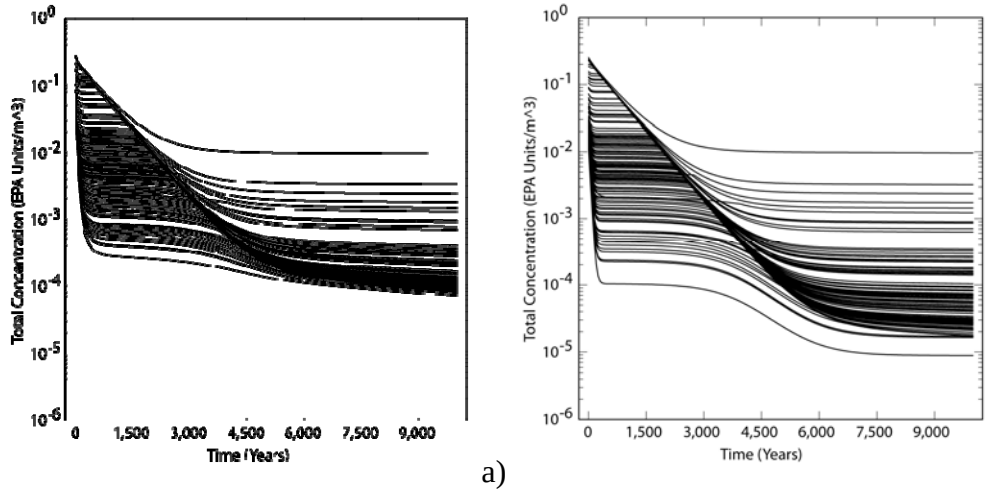

Figure 11. Total radionuclide concentration using the a) modified PANEL code with the test case inventory and b) PANEL version 4.03 with the WIPP baseline inventory (Garner and Leigh 2005).

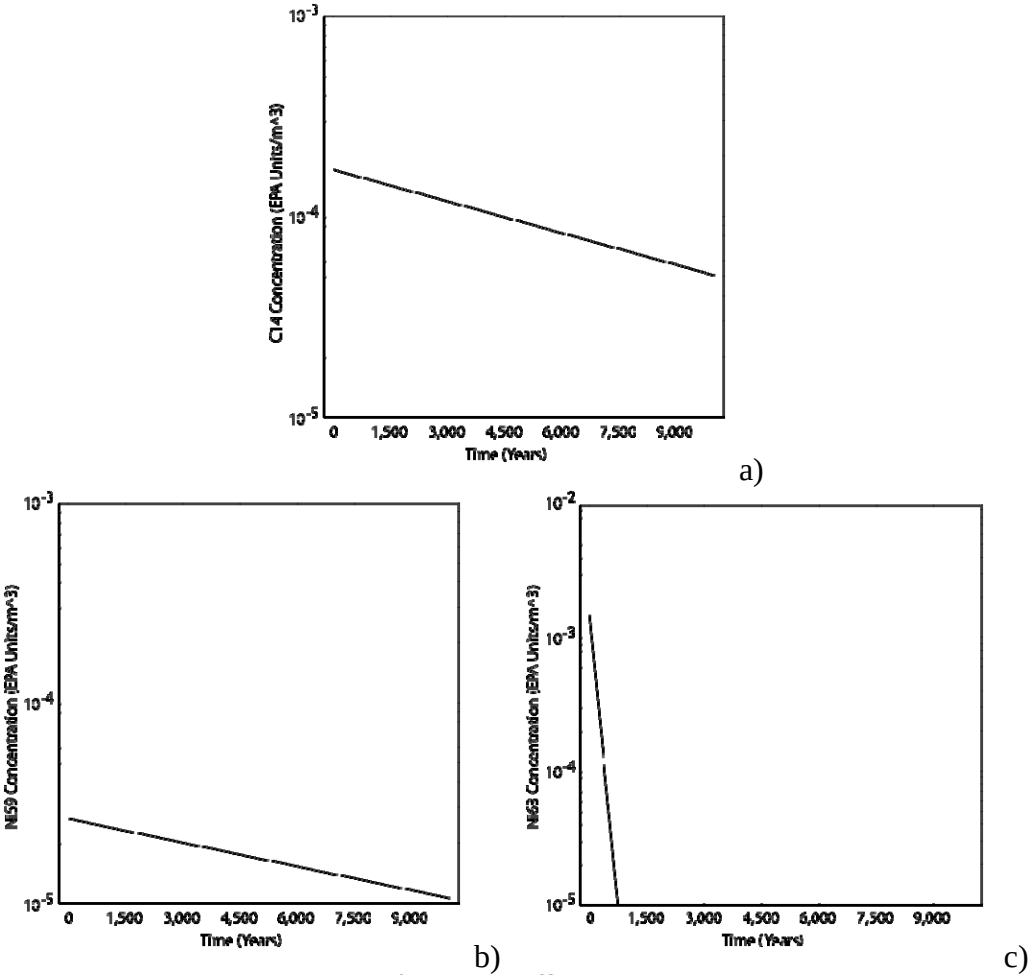

Figure 12. Concentration of a) ^{14}C, b) ^{59}Ni and c) ^{63}Ni using the modified PANEL code with the Case 4 inventory.

The increase in the total concentration is mainly due to the ^{14}C, ^{59}Ni and ^{63}Ni in waste stream 4. Figure 12 shows the normalized concentration of ^{14}C, ^{59}Ni and ^{63}Ni as a function of time for Case 4. A single solubility value is used for these radionuclides which is sufficiently high, such that the concentration is limited by the inventory and not the solubility limit. As seen in Figure 12, the concentration of the ^{14}C is of the order of 1.E-04 EPA Units/m^3, the ^{59}Ni is of the order of 1.E-05 EPA Units/m^3, and the concentration of the ^{63}Ni starts out at ~1.E-03 EPA Units/m^3, but then sharply decreases. The effect from the ^{14}C, ^{59}Ni and ^{63}Ni on the total concentration for Case 4 can be seen in the minimum of the 100 sets, as it is dominated by the ^{63}Ni concentration for times before ~1,000 years and by the sum of the ^{14}C and ^{59}Ni concentrations for times after ~1,000 years (see Figure 11).

4.2.1.5 Case T (Group 1 Waste Total)

Adding Group 1 GTCC LLW and DOE GTCC-like waste streams 1, 2, 3 and 4 to the WIPP inventory significantly increased the total radionuclide concentration. Figure 13 shows the total concentration as a function of time for 100 sets, comparing the results for Case T and the modified PANEL code with the PANEL version 4.03 results using the WIPP baseline inventory (Garner and Leigh 2005). Many radionuclides use a distribution for the solubility limit to capture the uncertainty, and so 100 sets with different solubility limits for those radionuclides are used, while for other radionuclides, a single solubility is used and so the same value is used in each of the 100 sets. The total concentration is a sum of all the radionuclide concentrations and so will generally decrease with time. As seen in Figure 13, the total concentration for the Case T is significantly increased compared to the WIPP baseline. Case T represents the sum of Cases 1, 2, 3 and 4 and as Case 1 dominates the total activity (Table 6), the results are very similar to the results shown for Case 1.

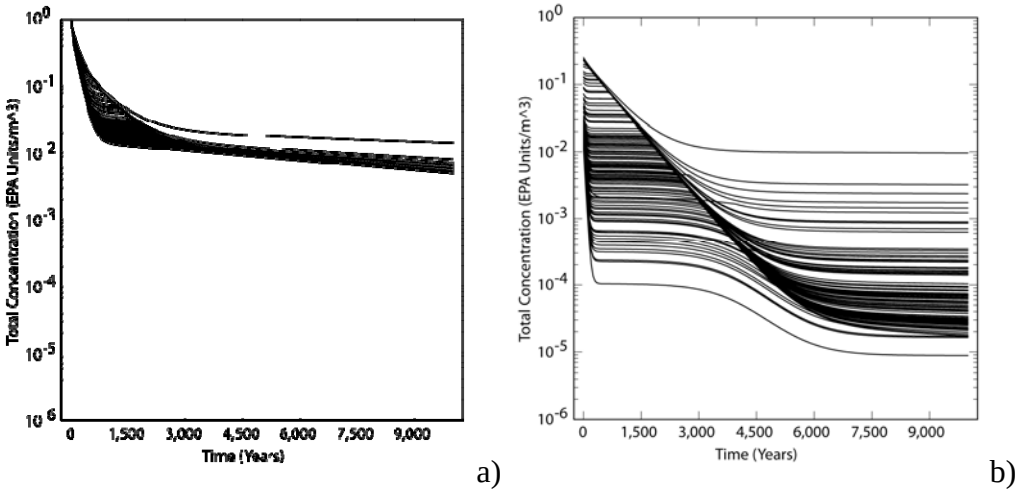

Figure 13. Total radionuclide concentration using the a) modified PANEL code with Case T inventory and b) PANEL version 4.03 with the WIPP baseline inventory (Garner and Leigh 2005).

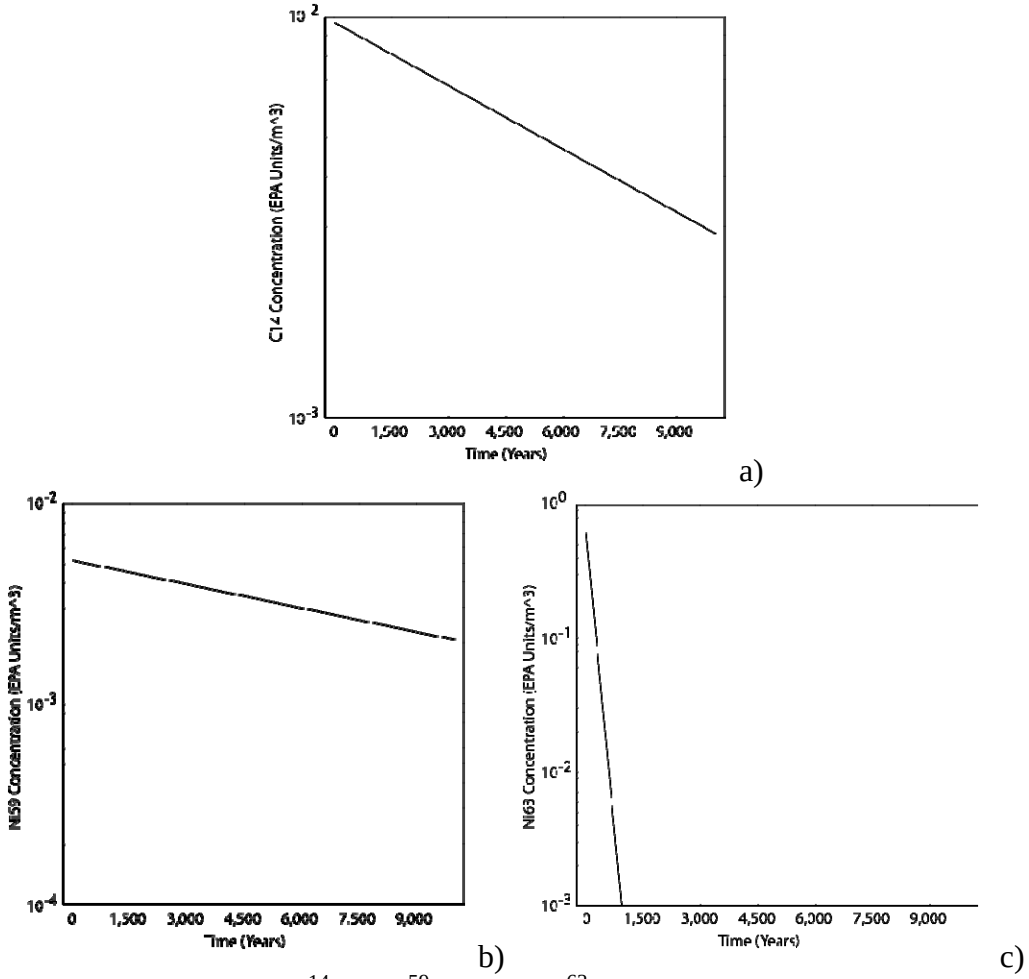

Figure 14. Concentration of a) ^{14}C, b) ^{59}Ni and c) ^{63}Ni using the modified PANEL code with Case T inventory.

The increase in the total concentration is mainly due to the ^{14}C, ^{59}Ni and ^{63}Ni in the waste streams. Figure 14 shows the normalized concentration of ^{14}C, ^{59}Ni and ^{63}Ni as a function of time for Case T. A single solubility value is used for these radionuclides which is sufficiently high, such that the concentration is limited by the inventory and not the solubility limit. As seen in Figure 14, the concentration of the ^{14}C ranges from 2.E-03 to 9.E-03 EPA Units/m^3, the ^{59}Ni concentration is of the order of 1.E-03 EPA Units/m^3, while the concentration of the ^{63}Ni starts out at ~5.E-01 EPA Units/m^3, but then sharply decreases. The effect from the ^{14}C, ^{59}Ni and ^{63}Ni on the total concentration for Case T can be seen in the minimum of the 100 sets, as it is dominated by the ^{63}Ni concentration for times before ~1,000 years and by the sum of the ^{14}C and ^{59}Ni concentrations for times after ~1,000 years (see Figure 13).

4.2.2 EPAUNI results

The EPAUNI code is the computational code that generates the normalized activity per volume as a function of time for use in calculating potential direct solid releases from the repository. The output from the EPAUNI code is the normalized release of radionuclides per volume of solid released. The normalized release concentrations that result from the EPAUNI code with

the addition of the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP inventory are discussed below.

As the concentrations are used in the direct solid release mechanism modeling, an increase in the concentration will result in an increase in the cumulative release. The normalized concentrations that resulted from the addition of waste streams 1, 2, 3 and 4 showed a modest increase compared with the baseline WIPP PA. The details of the EPAUNI results for each individual case are given below. For ease of discussion, the EPAUNI code results for the CH and RH waste are combined together below.

4.2.2.1 Case 1 (GTCC LLW Activated Metal)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 1 to the WIPP inventory increased the total radionuclide concentration. The average normalized activity for solid releases as a function of time for Case 1 compared with the results from the CRA-2004 PABC are shown in Figure 15. The difference between the two curves is the greatest at 0 years and decreases dramatically by 1,000 years where the difference remains fairly constant with time.

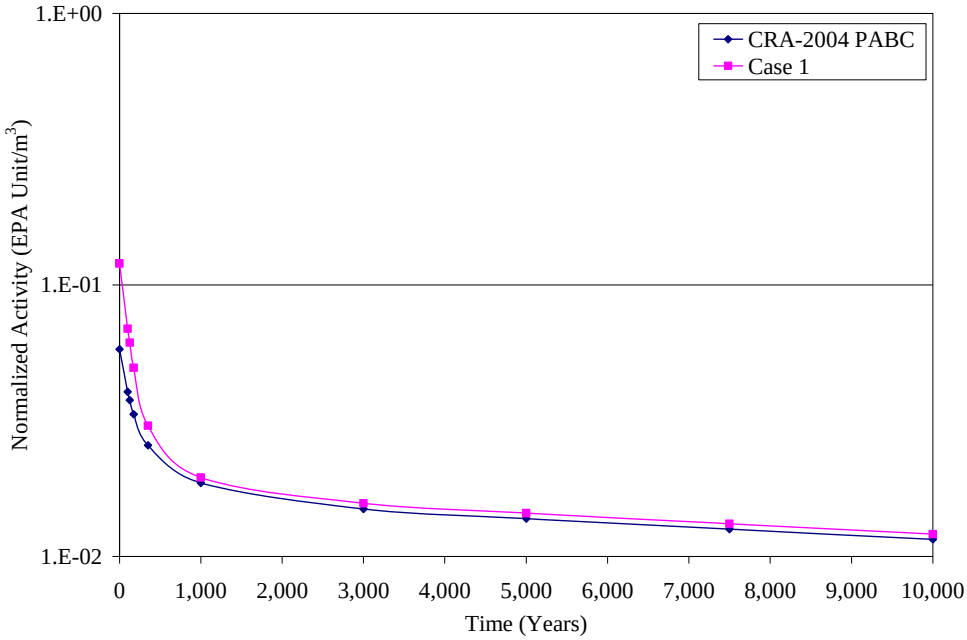

Figure 15. Normalized activity for solid releases as a function of time for Case 1 compared with the CRA-2004 PABC (Fox 2005).

4.2.2.2 Case 2 (GTCC LLW and DOE GTCC-like Sealed Sources)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 2 to the WIPP inventory decreased the total radionuclide concentration. The average normalized activity for solid releases as a function of time for Case 2 compared with the results from the CRA-2004 PABC are shown in Figure 16. There is little difference between the two curves until ~1,000 years when the normalized activity for Case 2 drops below the CRA-2004 PABC and then the

difference remains fairly constant with time. The decrease in total radionuclide concentration is due mainly to the increase in the updated f_w and the low concentration of radionuclide per volume in the Group 1 GTCC LLW and DOE GTCC-like waste stream 2.

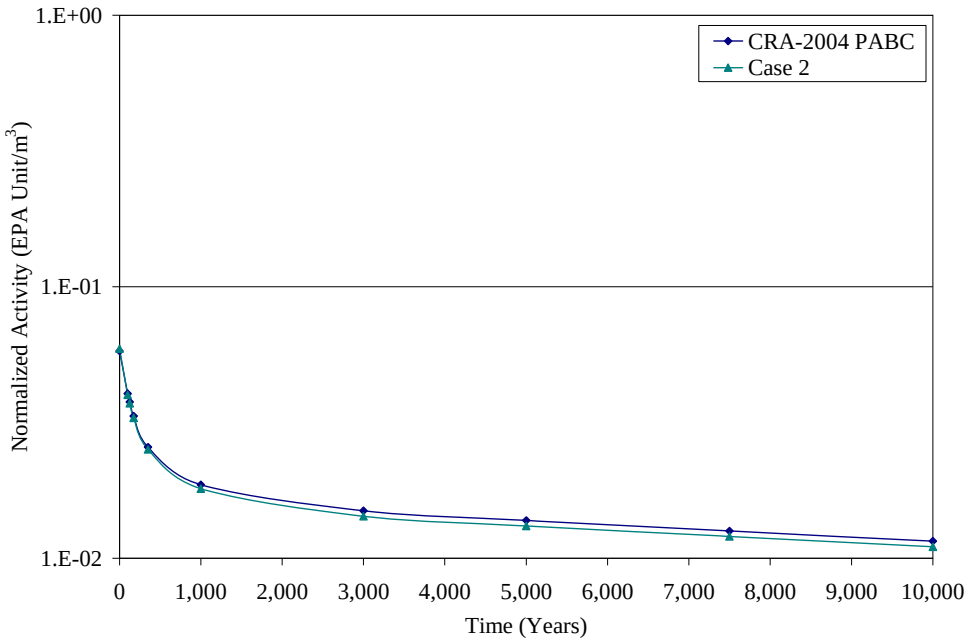

Figure 16. Normalized activity for solid releases as a function of time for Case 2 compared with the CRA-2004 PABC (Fox 2005).

4.2.2.3 Case 3 (DOE GTCC-like Activated Metal)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 3 to the WIPP inventory did not significantly affect the total radionuclide concentration. The average normalized activity for solid releases as a function of time for Case 3 compared with the results from the CRA-2004 PABC are shown in Figure 17. There is no apparent difference between the two curves for the entire 10,000 year period. This is due to the low volume and activity of the Group 1 GTCC LLW and DOE GTCC-like waste stream 3.

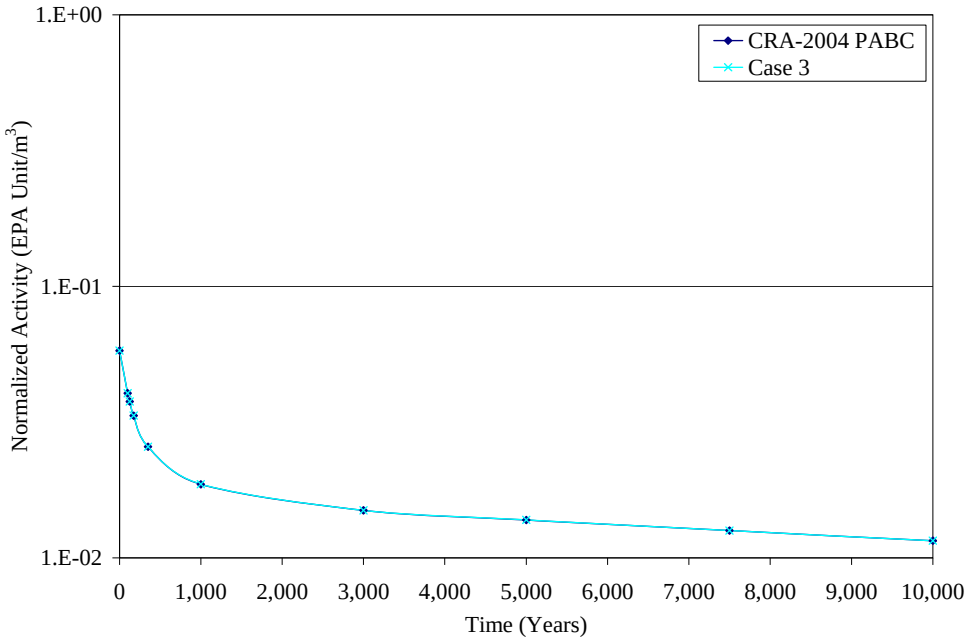

Figure 17. Normalized activity for solid releases as a function of time for Case 3 compared with the CRA-2004 PABC (Fox 2005).

4.2.2.4 Case 4 (GTCC LLW and DOE GTCC-like Other Waste)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 4 to the WIPP inventory did not significantly affect the total radionuclide concentration. The average normalized activity for solid releases as a function of time for Case 4 compared with the results from the CRA-2004 PABC are shown in Figure 18. The little difference between the two curves which indicates that the radionuclide concentration of the Group 1 GTCC LLW and DOE GTCC-like waste stream 4 is similar to the WIPP inventory.

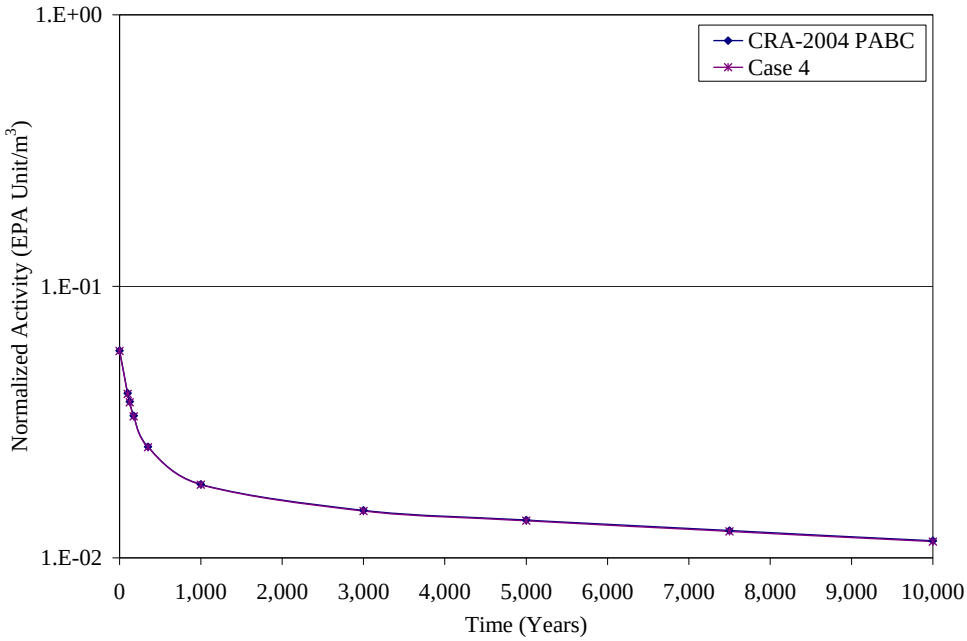

Figure 18. Normalized activity for solid releases as a function of time for Case 4 compared with the CRA-2004 PABC (Fox 2005).

4.2.2.5 Case T (Group 1 Waste Total)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste streams 1, 2, 3 and 4 to the WIPP inventory increased the total radionuclide concentration. The average normalized activity for solid releases as a function of time for Case T compared with the results from the CRA-2004 PABC are shown in Figure 19. The difference between the two curves is the greatest at 0 years and decreases dramatically by 1,000 years where the difference remains fairly constant with time. Case T represents the sum of Cases 1, 2, 3 and 4 and as Case 1 dominates the total activity (Table 6), the results are very similar to the results shown for Case 1.

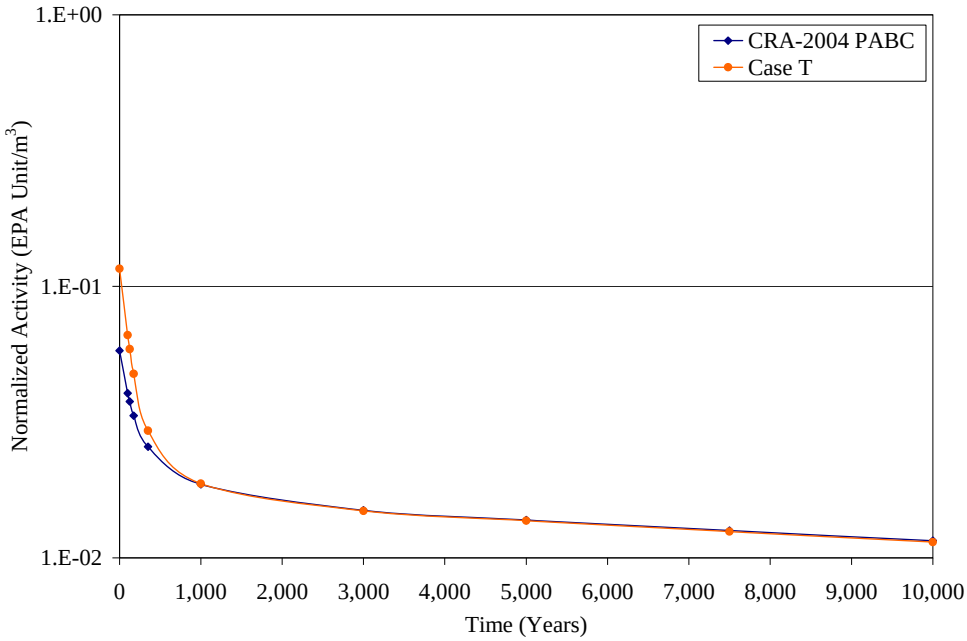

Figure 19. Normalized activity for solid releases as a function of time for Case T compared with the CRA-2004 PABC (Fox 2005).

4.2.3 CCDFGF results

The code CCDFGF assembles the release estimates from all other components of the WIPP PA system to generate CCDFs of releases. The CCDFs are then compared with the release limits stated in Section 191.13, less than a 10% chance of a normalized radionuclide release of one unit of waste (f_w) and a less than 0.1% chance of a normalized radionuclide release of ten times the unit of waste (f_w). The values of the mean total normalized release from the CCDFs for each case at the 10% and 0.1% probability are summarized below in Table 15. The incremental changes due to the addition of each Group 1 waste stream are also shown. As seen in Table 15, the incremental increases in the normalized releases to the IHI from adding the Group 1 GTCC LLW and DOE GTCC-like waste to the WIPP repository are not substantial enough to jeopardize the WIPP repository compliance with the release limits. The results for each individual case are discussed below in more detail.

Table 15. Mean Total Normalized Release at the 10% and 0.1% probability level for each case compared the CRA-2004 PABC (Vugrin and Dunagan 2005).

Case	10% probability level	Difference from PABC	0.1% probability level	Difference from PABC
CRA-2004 PABC	0.09	-	0.57	-
Case 1	0.17	0.08	1.55	0.98
Case 2	0.10	0.01	0.66	0.09
Case 3	0.10	0.01	0.67	0.10
Case 4	0.10	0.01	0.69	0.12
Case T	0.17	0.08	1.57	1.01
Max Allowable	1.00		10.00	

4.2.3.1 Case 1 (GTCC LLW Activated Metal)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 1 to the WIPP inventory increased the mean total release CCDF at all probabilities. The mean total release CCDF for Case 1 compared with the results from the CRA-2004 PABC are shown in Figure 20. The increase is mainly due to the increase in the normalized radionuclide concentration for brine release shown in section 4.2.1.1, while the increase in the CH area contributed as well. As seen in Figure 20, at the 10% probability level, the mean total normalized release increased from 0.09 to 0.17, while at the 0.1% probability level, the mean total normalized release increased from 0.57 to 1.55, which are both well below the release limits.

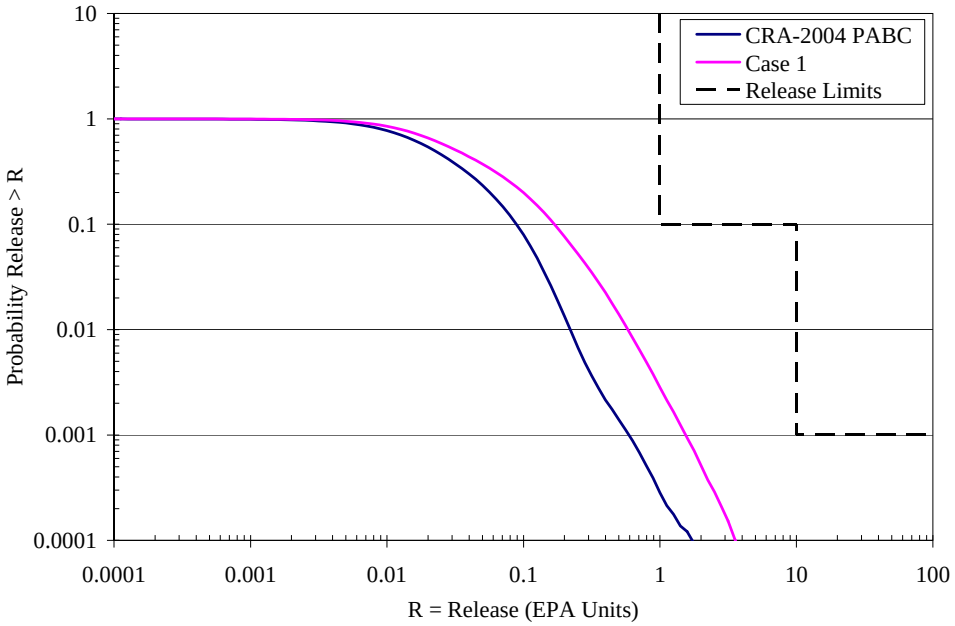

Figure 20. Mean total release CCDF for Case 1 compared with the CRA-2004 PABC (Vugrin and Dunagan 2005).

4.2.3.2 Case 2 (GTCC LLW and DOE GTCC-like Sealed Sources)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 2 to the WIPP inventory slightly increased the mean total release CCDF at all probabilities. The mean total release CCDF for Case 2 compared with the results from the CRA-2004 PABC are shown in Figure 21. The increase is mainly due to the increase in the CH area. As seen in Figure 21, at the 10% probability level, the mean total normalized release increased from 0.09 to 0.10, while at the 0.1% probability level, the mean total normalized release increased from 0.57 to 0.66, which are both well below the release limits.

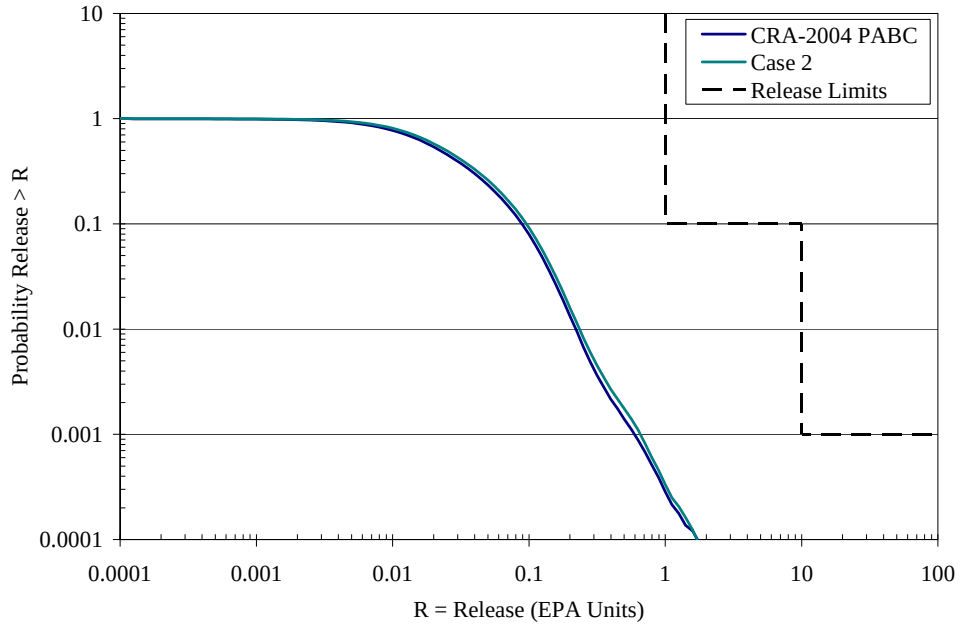

Figure 21. Mean total release CCDF for Case 2 compared with the CRA-2004 PABC (Vugrin and Dunagan 2005).

4.2.3.3 Case 3 (DOE GTCC-like Activated Metal)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 3 to the WIPP inventory slightly increased the mean total release CCDF at all probabilities. The mean total release CCDF for Case 3 compared with the results from the CRA-2004 PABC are shown in Figure 22. The increase is mainly due to the increase in the CH area. As seen in Figure 22, at the 10% probability level, the mean total normalized release increased from 0.09 to 0.10, while at the 0.1% probability level, the mean total normalized release increased from 0.57 to 0.67, which are both well below the release limits.

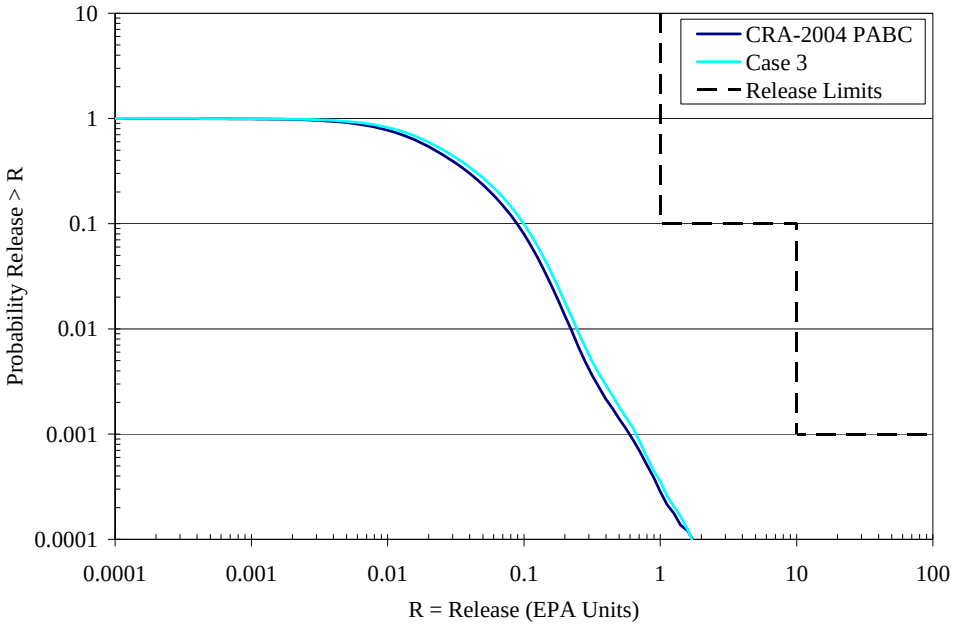

Figure 22. Mean total release CCDF for Case 3 compared with the CRA-2004 PABC (Vugrin and Dunagan 2005).

4.2.3.4 Case 4 (GTCC LLW and DOE GTCC-like Other Waste)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste stream 4 to the WIPP inventory slightly increased the mean total release CCDF at all probabilities. The mean total release CCDF for Case 4 compared with the results from the CRA-2004 PABC are shown in Figure 23. The increase is mainly due to the increase in the CH area. As seen in Figure 23, at the 10% probability level, the mean total normalized release increased from 0.09 to 0.10, while at the 0.1% probability level, the mean total normalized release increased from 0.57 to 0.69, which are both well below the release limits.

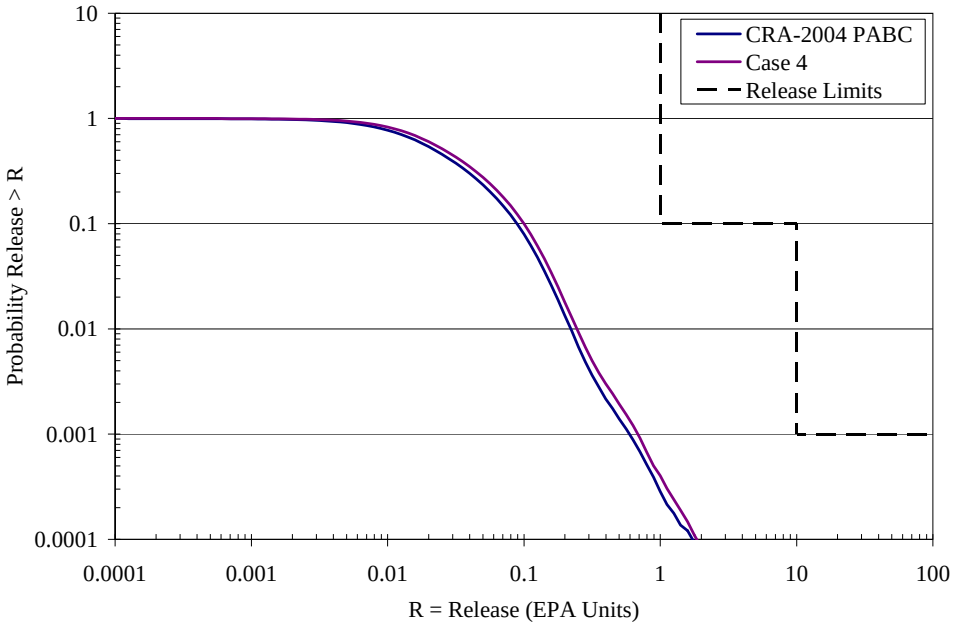

Figure 23. Mean total release CCDF for Case 4 compared with the CRA-2004 PABC (Vugrin and Dunagan 2005).

4.2.3.5 Case T (Group 1 Waste Total)

Adding the Group 1 GTCC LLW and DOE GTCC-like waste streams 1, 2, 3 and 4 to the WIPP inventory increased the mean total release CCDF at all probabilities. The mean total release CCDF for Case T compared with the results from the CRA-2004 PABC are shown in Figure 24. Case T represents the sum of Cases 1, 2, 3 and 4 and as Case 1 dominates the total activity (Table 6), the results are very similar to the results shown for Case 1. The increase is mainly due to the increase in the normalized radionuclide concentration for brine release shown in section 4.2.1.5, while the increase in the CH area contributed as well. As seen in Figure 24, at the 10% probability level, the mean total normalized release increased from 0.09 to 0.17, while at the 0.1% probability level, the mean total normalized release increased from 0.57 to 1.57, which are both well below the release limits.

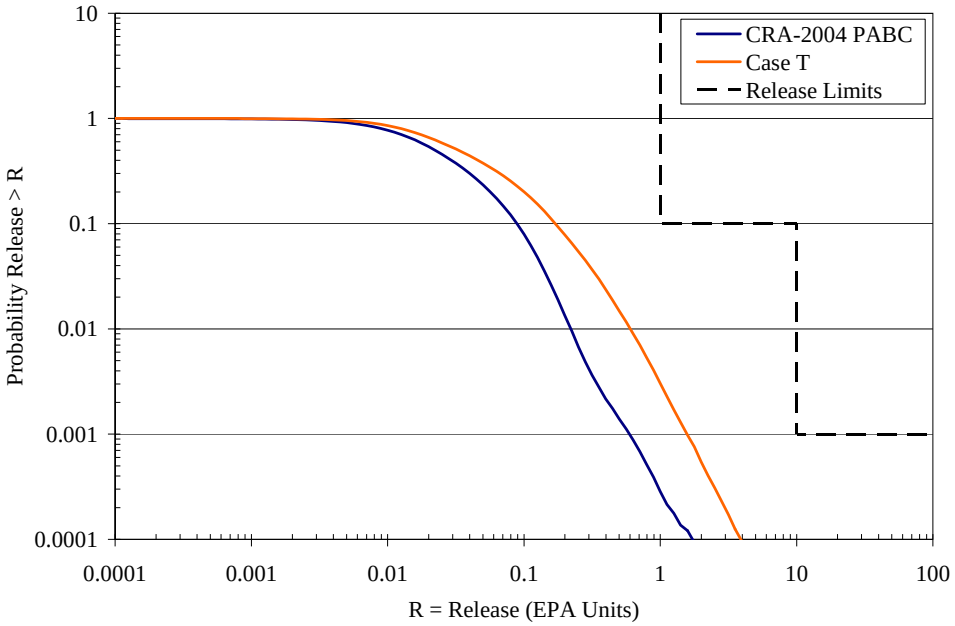

Figure 24. Mean total release CCDF for Case T compared with the CRA-2004 PABC (Vugrin and Dunagan 2005).

4.3 LONG-TERM STABILITY

Long-term stability is also a requirement of the WIPP repository. Analyses of the potential excavation-induced subsidence were conducted and found that it would not be significant due to the depth of the repository and low extraction ratio (U.S. DOE 1996). Furthermore, active institutional controls are to be emplaced such that the repository will not be disturbed for at least 100 years. Therefore, it was determined that there are no long-term stability issues for the WIPP repository. The addition of the GTCC LLW and DOE GTCC-like waste will not adversely affect the long-term stability, as the same emplacement strategy is used.

5. REFERENCES

Argonne (2006). Requirements for the Environmental Impact Statement Analysis of Greater Than Class C Waste Disposal. ERMS 545172. Argonne National Laboratory.

Argonne (2008). Supplement to Greater-Than-Class C (GTCC) Low-Level Radioactive Waste and U.S. Department of Energy GTCC-Like Waste Inventory Reports. Argonne National Laboratory.

CIS-US (2006). IBL-437 Blood Irradiator & DoseWriter Webpage Available at: http://www.cisusinc.com/iblbody.htm. ERMS 545196. Bedford, MA.

Clayton, D.J. and J.W. Garner (2008). Validation of Modified PANEL Code Used for the Greater-Than-Class-C Low-Level Waste in WIPP Post-Closure Performance Calculations. ERMS 548328. Sandia National Laboratories. Carlsbad, NM.

Cotsworth, E. (2005). EPA Letter on Conducting the Performance Assessment Baseline Change (PABC) Verification Test. ERMS 538858. U.S. EPA, Office of Radiation and Indoor Air, Washington, D.C.

Fox, B. (2005). Analysis Package for EPA Unit Loading Calculations: Performance Assessment Baseline Calculation, Revision 0. ERMS 540378. Sandia National Laboratories. Carlsbad, NM.

Garner, J.W. and C.D. Leigh. (2005). Analysis Package for PANEL, CRA-2004 Performance Assessment Baseline Calculation, Revision 0. ERMS 540572. Sandia National Laboratories. Carlsbad, NM.

Holbert, K.E. (2006). Radioactive Decay. Webpage available at: http://www.eas.asu.edu/~holbert/eee460/RadioactiveDecay.pdf.

KAPL (2002). Nuclides and Isotopes, Chart of the Nuclides, Sixteenth Edition. KAPL, Inc.

Leigh, C.D. and B. Fox. (2005). Radionuclides Expected to Dominate Potential Releases in the Performance Assessment Baseline Calculation. Revision 0. ERMS 539643. Sandia National Laboratories. Carlsbad, NM.

Leigh, C.D., J.F. Kanney, L.H. Brush, J.W. Garner, G.R. Kirkes, T.S.Lowry, M.B. Nemer, J.S. Stein, E.D. Vugrin, S. Wagner, and T.B. Kirchner. (2005). 2004 Compliance Recertification Application Performance Assessment Baseline Calculation, Revision 0. ERMS 541521. Sandia National Laboratories. Carlsbad, NM.

Leigh, C.D. and J.R. Trone. (2005). Calculation of the Waste Unit Factor for the Performance Assessment Baseline Calculation. Revision 0. ERMS 539613. Sandia National Laboratories. Carlsbad, NM.

Lowry, T.S. (2005) Analysis Package for Salado Transport Calculations, CRA-2004 PA Baseline Calculation, Revision 0. ERMS 541084. Sandia National Laboratories. Carlsbad, NM.

MacKinnon, R.J., and G. Freeze. (1997a). Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison with the Compliance Certification Application Calculations, Revision 1. ERMS 422595. Sandia National Laboratories. Albuquerque, NM.

MacKinnon, R.J., and G. Freeze. (1997b). Summary of Uncertainty and Sensitivity Analysis Results for the EPA-Mandated Performance Assessment Verification Test, Rev. 1. ERMS 420669. Sandia National Laboratories. Albuquerque, NM.

MacKinnon, R.J., and G. Freeze. (1997c). Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison with the Compliance Certification Application Calculations, Revision 1. ERMS 414880. Sandia National Laboratories. Albuquerque, NM.

SNL (2007). Two Technology Conceptual Designs for Disposal of GTCC LLW, Task 3.4, Develop Conceptual Designs, Revision 1. ERMS 548059. Sandia National Laboratories. Carlsbad, NM.

SNL (2008a). Basis Inventory for Greater-Than-Class-C Low-Level Radioactive Waste Environmental Impact Statement Evaluations, Task 3.2, Establish Basis Inventory, Revision 1. ERMS 549003. Sandia National Laboratories. Carlsbad, NM.

SNL (2008b). GTCC LLW Environmental Impact Statement: Pre-Closure Assessment Data Package: Waste Isolation Pilot Plant. Revision 3. ERMS 550193. Sandia National Laboratories. Carlsbad, NM.

U. S. DOE (1994). Greater-Than-Class C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics. DOE/LLW-114 Rev. 01 United States Department of Energy. Idaho Falls, I.D.

U. S. DOE (1996). Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant. DOE/CAO-1996-2184. U.S. Department of Energy, Waste Isolation Pilot Plant Carlsbad Area Office. Carlsbad, NM.

U. S. DOE (2004). Title 40 CFR Part 191 Compliance Recertification Application for the Waste Isolation Pilot. DOE/WIPP 2004-3231. U.S. Department of Energy Waste Isolation Pilot Plant, Carlsbad Field Office. Carlsbad, NM.

U. S. DOE (2006). CH-TRAMPAC, Revision 2. United States Department of Energy Carlsbad Field Office. Carlsbad, NM.

Vugrin, E.D. and S. Dunagan. (2005). Analysis Package for CCDFGF, CRA-2004 Performance Assessment Baseline Calculation, Revision 0. ERMS 540771. Sandia National Laboratories. Carlsbad, NM.