ISO-2 Project WIPP Independent Oversight – DE-AC30-06EW03005

EVALUATION OF THE QUALITY AND REALISM OF THE PERFORMANCE ASSESSMENT

June 2007

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ISO-2 Project
Carlsbad, NM

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TABLE OF CONTENTS

ACRONYMS

BRAGFLO	Brine and Gas Flow Model
CBFO	Carlsbad Field Office
CCA	Compliance Certification Application
CCDF	Complementary Cumulative Distribution Functions
CFR	Code of Federal Regulations
CH	Contact Handled
CPR	Cellulosics, plastic and rubber
CRA	Compliance Recertification Application
DOE	Department of Energy
DP	Disturbed Performance
DRZ	Disturbed Rock Zone
EDTA	Ethylenediaminetetraacetic Acid
EP	Events and Processes
EPA	Environmental protection Agency
FEPs	Features, Events, and Processes
H	Human-Initiated
HCN	Historical, Current, and Near-Future Human Activities
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LWA	Land Withdrawal Act
MgO	Magnesium Oxide
N	Natural
NUTS	Nuclide Transport System Model
PA	Performance Assessment
RH	Remote Handled
SKI	*Statens Kärnkraftinspektion*
SNL	Sandia National Laboratories
SO-C	Screen Out – Consequence
SO-P	Screen Out – Probability
SO-R	Screen Out– Regulatory
T-field	Culebra transmissivity
TRU	Transuranic
UP	Undisturbed Performance
W	Waste and Repository-Induced
WIPP	Waste Isolation Pilot Plant

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I. PURPOSE AND SCOPE

The purpose of this report is to review documentation and other information concerning the requirements, assumptions, and inputs for the performance assessment (PA) prepared for the Waste Isolation Pilot Plant (WIPP). This report provides a summary of requirements for the PA, an overview of the development of the PA, and bases for the inputs. The authors have evaluated the development of the PA—including selected reference documents and the review comments and requirements established by the Environmental Protection Agency (EPA)—and have provided conclusions and recommendations. Materials reviewed include text and selected appendices of selected applicable laws and regulations; the *Compliance Certification Application (CCA);*[1] the *2004 WIPP Compliance Recertification Application (CRA);*[2] scientific design and implementation documents; technical papers and peer review reports; correspondence with the EPA; and presentations made to PECOS by personnel from the U.S. Department of Energy (DOE), Carlsbad Field Office (CBFO) and their contractors and subcontractors supporting the WIPP.

II. BACKGROUND

During the process of development and approval of the WIPP, extensive efforts were expended to establish acceptable operating and closure conditions and requirements. These efforts culminated in the Waste Isolation Pilot Plant Land Withdrawal Act (LWA),[3] as amended. The LWA required the EPA to establish both the standards for radioactive waste disposal for the WIPP and requirements for certification of compliance with those standards. EPA published those requirements in two regulations: 40 CFR 191[4] and 40 CFR 194.[5]

The requirement to conduct a PA for the WIPP is stated in the LWA. Standards and other limiting conditions to be used in developing the PA are presented in 40 CFR 191, and specific instructions or requirements for the conduct of the PA are listed in 40 CFR 194.

Major conditions imposed upon the performance assessment by either the LWA, 40 CFR 191 or 40 CFR 194 include:

1. Curie Limit for Remote Handled TRU Waste = 5.1 million curies (LWA)

2. Volumetric Capacity Limit for TRU Waste = 6.2 million cubic feet (175,546 cubic meters) (LWA). This is further divided into 5.950 million cubic feet of contact-handled (CH) and 250,000 cubic feet of remote-handled (RH) TRU waste.

3. Time Frame for Long-Term Assessment = 10,000 years (40CFR191)

4. Allowable Duration of Active Institutional Controls = 100 years (40CFR191)

5. Exposure Standard (40 CFR 191) = 25 millirems whole body annual committed effective dose for the operational period and 15 millirems annual committed effective dose for the long term. *(Annual committed effective dose means the committed effective dose resulting from one-year intake of radionuclides released plus the annual effective dose caused by direct radiation from facilities or activities associated with the WIPP.)*

6. Barriers (LWA and 40 CFR 191). Both documents indicate that engineered barriers ***shall be included.*** However, the definitions of barriers differ between the two, with 40 CFR 191 being more restrictive than the LWA.

7. Updates (LWA). The PA must be updated as needed as a part of the 5-year recertification cycle. The information required to be submitted is defined in 40 CFR 194.

The PA process is used to predict whether there may be any release of radionuclides in excess of established regulatory limits from the WIPP to the environment within 10,000 years after closure. The PA must provide information and address conditions and issues identified in 40 CFR 191 and 40 CFR 194. If the PA demonstrates compliance with identified conditions and issues, the EPA will then certify the WIPP for operation. Essentially, the approach, performance, and results of the PA comprise the principal basis for both public acceptance and EPA certification of the WIPP for TRU waste disposal as well as recertification.

The PA was initiated with a consideration of all known possible variables that could affect the release of radionuclides. These variables were reduced to a final list of 90, which were then subdivided into three sets: features, events, and processes (FEPs). Features are typically physical items such as geology. Events are usually occurrences, such as seismic activity and climate change, and processes are activities that occur, such as gas generation due to steel corrosion. These variables are combined into 24 conceptual models that depict what might occur over 10,000 years. The results of these conceptual models are then predicted using one or more mathematical models developed to simulate actual conditions. These mathematical models predict changes in variables—such as groundwater flow, natural closure of the repository due to salt creep, chemical, physical, and biological actions on the transuranic waste, etc.—that are expected to occur at the WIPP over a period of 10,000 years. Information is gathered from actual laboratory data, field observations, and other sources and is then applied to the selected FEPs, models, and performance of the disposal system in order to forecast any potential release and exposure paths for 10,000 years. Results of these analyses and calculations are then evaluated for accuracy and sensitivity using two different statistical approaches: 1) a Monte Carlo analysis applied to each model and 2) a complementary cumulative design function analysis applied to the integrated sum of all the models.

III. SUMMARY OF FINDINGS

The PA represents the evaluation and integration of gathered, measured, and generated historical (anecdotal) and scientific data that are relative to the processes and events that might affect the WIPP and consequently result in a release of radioactivity to the accessible environment which may be greater than the standards established by the EPA. The EPA has recognized that it is difficult (though plausible) to forecast geological, hydrogeological, and climatic conditions 10,000 years into the future, an observation that constitutes a significant part of the effort set forth in the PA to predict how the waste deposited in the WIPP may behave over that same time period. Nevertheless, both scientists and the general public recognize that any attempts to predict the future are fraught with uncertainties. Therefore, this review of the PA concentrates on two factors:

1. The DOE's design and implementation of the PA
2. The quality or realism of the inputs used for key variables

IIIA. DESIGN AND IMPLEMENTATION

The following sections discuss FEPs, conceptual models, computational models, model input data, assumptions made for the models, and the realism of major variables.

Features, Events, and Processes (FEPs)

As a starting point, the DOE assembled a list of potentially relevant FEPs from the compilation developed for the Swedish Nuclear Power Inspectorate *Statens Kärnkraftinspektion* (SKI). The SKI list was based on a series of FEP lists developed for other disposal programs and is considered the best documented and most comprehensive starting point for the WIPP. For the SKI study, an initial, raw FEP list was compiled based on ***nine*** different FEP identification studies. Items clearly not applicable to the WIPP were removed, and items not applicable to Sweden that may be applicable to WIPP were added. The initial WIPP list for consideration, which contained over 200 FEPs, was then evaluated for inclusion into the PA models. The screening process drew upon regulatory requirements, probabilities, and consequences to determine the final FEP list used to develop the conceptual models. As an example, one of the retained features was *Stratigraphy*, a branch of geology specifically concerned with the arrangement of layered rocks. *Seismic Activity* is an example of an event that was retained to determine if an earthquake would allow exposures to occur. Also retained was a process called *Gases from Metal Corrosion*, which would contribute internal pressure to the repository.

Attachment 1 provides a listing of the retained FEPs along with a description and listing of the conceptual model that incorporates each FEP. To ensure PA calculations account for important aspects of the disposal system, FEPs considered potentially important to the disposal system are identified and used as tools to determine what phenomena and components of the disposal system can and should be dealt with in PA calculations.

The origin of FEPs is related to the EPA’s radioactive waste disposal standard’s requirement to use PA methodology. The DOE was required to demonstrate that the WIPP complied with the containment requirements of 40 CFR 191.13, which require the DOE to use the PA to demonstrate that the probabilities of cumulative radionuclide releases from the disposal system during the 10,000 years following closure will fall below specified limits. The PA analyses supporting this determination must be quantitative and must consider uncertainties caused by all “Significant Processes and Events” that may affect the disposal system—including inadvertent human intrusion into the repository during the future.

FEP Screening

The purpose of FEP screening is to identify which of the 200 FEPs originally singled out for consideration for the WIPP should be accounted for in PA calculations, and which FEPs need not be further considered. The DOE’s process of removing FEPs from consideration in PA calculations involved the structured application of explicit screening criteria. The criteria used to screen FEPs are explicit regulatory exclusions (SO-R), probability (SO-P), or consequence (SO-C), all derived from regulatory requirements. FEPs that met the SO-R, SO-P, or SO-C criteria were retained for inclusion in PA calculations. The final WIPP list (*Attachment 1*) contains 90 FEPs. The screening criteria and process appear to be reasonable and logical.

FEPs are classified as either undisturbed performance (UP) or disturbed performance (DP). Undisturbed performance is defined in 40 CFR 191.12 as the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events. FEPs classified as UP are accounted for in calculations of undisturbed performance of the disposal system. The UP FEPs are accounted for in the PA calculations to evaluate compliance with the containment requirements in 40 CFR 191.13. Undisturbed PA calculations are also used to demonstrate compliance with individual and groundwater protection requirements of 40 CFR 191.15 and 40 CFR 191 Subpart C, respectively.

FEPs classified as DP are accounted for only in assessment calculations for disturbed performance. The DP FEPs that remained following the screening process relate to potential disruptive effects of future drilling and mining events in the controlled area. Consideration of both DP and UP FEPs is required to evaluate compliance with 40 CFR 191.13.

FEPs are discussed under the following categories: natural (N) FEPs; human-initiated (H) events and processes (EP); and waste- and repository-induced (W) FEPs. FEPs are also considered according to the timeframes during which they may occur. Due to regulatory requirements concerning human activities, two time periods were used when evaluating H EPs. These timeframes were defined as historical, current, and near-future human activities (HCN) and future human activities (Future).

In some cases, an FEP influences a particular model. As an example, *Organic Complexation* influences the chemical condition model by recognizing certain chemicals such as acetate, citrate, oxalate, and Ethylenediaminetetraacetic Acid (EDTA) as the only water-soluble and actinide complexing organic ligands present in sufficient quantities to affect chemical conditions. In other cases, an FEP is used to establish boundary conditions for a model. As an example, *Stratigraphy* directly influences the disposal system model, but is used in the transport of dissolved actinides in the Culebra model for thickness and lateral extent.

The FEP for *Loss of Records* has been used for the limits of passive controls and was employed during the screening process rather than applied directly to a model.

FEP Category Drivers

DOE divided the retained FEPs into three categories: 1) scientific-based, 2) regulatory requirement, and 3) agency requirement. As FEPs were incorporated into various models, this division proved to be a confusing task due to the crossover issue. For instance, the FEP for waste inventory was used to derive actinide solubilities and gas generation rates in the calculations. Regulations only require the inventory to be analyzed to estimate exposures during releases and do not "dictate the inventory" beyond establishing maximum allowable waste volume and curies of RH TRU waste. With this in mind, all of the W FEPs were retained as scientific-based except for the ones listed in *Attachment 3*. Another FEP that proved troublesome was the Disturbed Rock Zone (DRZ). Originally, DOE used a constant permeability, which is the capacity of solid materials such as waste, rock, sediment, or soil, in order to allow fluids to pass through under specific conditions associated with the 10,000-year compliance period; but the EPA noted that the permeability range should be uncertain. To respond to EPA's comment, the DOE assigned a permeability range of 3.98×10^{-20} m^2 to 3.16×10^{-13} m^2 and a porosity range from 0.04 percent to 3.3 percent to the DRZ model. The DRZ effective porosity value for each realization (essentially an operation of the components that make up the PA) is equivalent to the sampled value for the Salado halite plus 0.0029. (The 0.0029 is the difference between the medians for the DRZ and the halite.) The DRZ model also receives inputs from other models, such as the Salado Interbeds, which use different permeability and porosity ranges due to changes resulting from pressure increases. The pressure-dependant changes in permeability for Salado Interbeds are supported by experiments performed at WIPP and in off-site laboratories.

40 CFR 194.25 requires DOE to consider potential future hydrogeologic, geologic, and climatic conditions over the regulatory timeframe. With this requirement, all N FEPs are of a regulatory nature, but are based upon gathered field or laboratory data, reasonable scientific theories (based on laboratory simulations), and empirical constants. Due to the general encompassing nature of the regulation and the approach used for the N FEPs, they were all categorized as "scientific."

40 CFR 194.32 requires that the PA include drilling and mining activities, and 40 CFR 194.33 stipulates that one must assume a "drilling intrusion" occurs during drilling activities. As shown in *Attachment 3*, 22 FEPs were categorized in the regulatory grouping, 16 of which were based strictly on the human initiated (H) scenario resulting from drilling or mining operations. Five FEPs from the waste category were included due to their relationship to mining or drilling activities. The final H was the Loss Of Records, retained due to the requirements of 40 CFR 194.41 and 194.43, which only allow active controls to be considered effective for 100 years after closure while passive controls can be considered relevant for several hundred years.

Five FEPs were categorized as being agency-driven and are from the W FEPs. Four of these are related to seal performance and characterization and were included because the seal FEPs were defined to include the panel closures. Option D panel closures were not included in the original PA, but EPA mandated their inclusion in the final PA and the updated PA. The fifth retained item for this category is the DRZ, which was retained because, as discussed above, EPA requires DOE to treat permeability for the DRZ as a variable over time instead of as a constant. All other W FEPs were retained under the scientific heading.

IIIB. FEP SENSITIVITY

The purpose of this section is to describe the qualitative sensitivity analysis to determine which FEPs are most important in terms of releases from WIPP to surface atmosphere. In determining the most sensitive FEPs, it is important to note that the waste inventory FEP has two regulatory constraints: It can contain no more than 5.2 million curies of RH TRU waste and no more than 6.2 million cubic feet of waste. For the PA, the volume of waste was determined by DOE to be limiting, resulting in only about 2.4 million curies emplaced in the WIPP. Thus, increases to the variable values used in the PA for the waste inventory FEP to values greater than the regulatory limits, which would have a direct impact on the releases from the WIPP to the surface atmosphere, are precluded from this sensitivity analysis.

Inasmuch as the only significant release to the surface atmosphere was due to a human-initiated (intrusion) event, the sensitivity analysis of FEPs was limited to the DP scenario. Also, the PA was constructed to meet the premise that if an FEP was increased or decreased, other FEPs affected by that change would be modified accordingly.

Outlined below are the conceptual models and FEPs that were used in the sensitivity analysis

FEP Analysis

The human intrusions that could produce significant radionuclide release occur through five mechanisms:

- Cuttings (W84)
- Cavings (W85)
- Spallings (W86)
- Direct brine releases, which include contaminated brine that may flow to the surface during drilling

- Long-term brine releases, which include the contaminated brine that may flow through a borehole after it is abandoned

It is interesting that the first three release mechanisms are considered W FEPs instead of H FEPs, since the only way they can occur is by the "human intrusion" event of drilling. The last two items represent multiple FEPs and basically fall into the category of human intrusion. Cuttings and cavings were combined into a single conceptual model, and spalling was developed as a single conceptual model.

Actinides may be mobilized in repository brine in two principal ways: 1) as dissolved species, and 2) as colloidal species. Model results indicate that essentially, all flow occurs into the Culebra (see *Figure 1*), which has been recognized since the early stages of site characterization as the most transmissive unit above the repository and the most likely pathway for subsurface transport.

The groundwater flow in the Culebra is modeled as a steady-state process; but two mechanisms that could affect flow in the future are:

1. Potash mining in the McNutt Potash Zone (hereafter referred to as the McNutt) of the Salado, which occurs now in the Delaware Basin outside the controlled area and may continue in the future. This could affect flow in the Culebra if subsidence over mined areas causes fracturing or other changes in rock properties.
2. Climatic changes during the next 10,000 years may also affect groundwater flow by altering recharge to the Culebra.

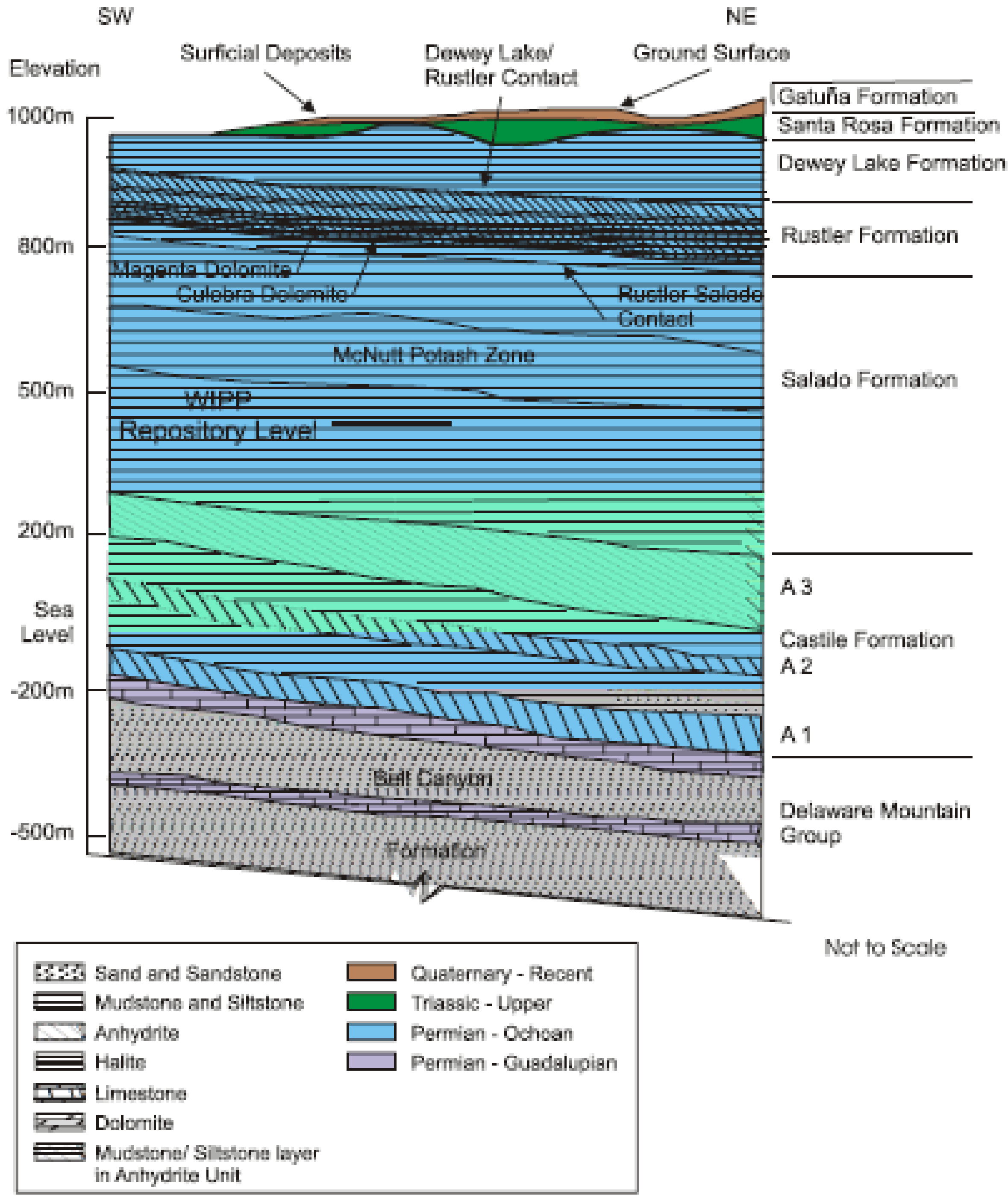

Figure 1. Geology of the WIPP (from CRA 2004)

Modeling, as supported by field tests and laboratory experiments, indicates that physical and chemical retardation will be extremely effective in reducing the amount of dissolved actinides that will reach the Culebra. In other words, the retardation reduces the quantity of actinides that could be dissolved. The Culebra transmissivity (T-field) was calibrated on the basis of 41 test locations (see *Appendix PA Attachment Tfield,* Figure-TFIELD 6 of the CRA for the well locations). As discussed in Section 6.4.6.2.2 of the CRA, the four types of colloids and colloidal-sized particles modeled to be introduced to the Culebra are microbes, mineral fragments, humic substances, and actinide intrinsic colloids. To investigate the impact of these four colloid types on radionuclide transport in the Culebra, an experimental program was developed and implemented at Sandia National Laboratory (SNL) with significant contributions from Lawrence Livermore National Laboratory (LLNL), Battelle National Laboratory, Los Alamos National Laboratory (LANL), and Florida State University. The EPA requires recertification documentation to include an update of additional analyses and results of laboratory experiments conducted by the DOE or its contractors as part of the WIPP program. (40 CFR 194.15[a][3]).

Experimental work has demonstrated that transport of colloidal actinides is not a significant mechanism in the Culebra due to geologic properties. As a result, actinide transport through the Culebra to the subsurface boundary of the controlled area is not a significant pathway for releases from the WIPP. Therefore, release to the surface is limited to an intrusion from drilling. (See Section 6.0.2.3.7 of the CRA)

The model "Creep Closure" uses porosity calculated over time by varying the rate of gas generation and gas production potential to construct a porosity surface representing changes in porosity as a function of pressure and time. As such, fluids that could affect closure are: brine that may enter the repository from the Salado or an intrusion borehole; air present in the repository when it is sealed; and gas produced by reactions occurring during waste degradation. The air in the enclosed room (assumed to be the entire volume of the room rather than volume adjusted for waste volumes in room) is evaluated from the beginning point in time in the gas generation equations. The amount of oxygen (O_2) generated from various equations during gas generation is also taken into account during the modeling histories. Results don't show O_2 generation arising as an issue. Closure and consolidation can be slowed by fluid or gas pressure in the repository. Gas will be generated by anoxic corrosion of steels and other iron-based alloys, and microbial consumption of celluloses, plastics, and other rubber materials (CPR). The anoxic corrosion is expected to produce hydrogen, and the microbial consumption is expected to produce carbon dioxide and methane. For purposes of calculating MgO requirements, EPA directed that the entire CPR carbon inventory is assumed to be converted to carbon dioxide (CO_2), which is theoretically possible if a sufficient amount of sulfate and other micronutrients exist in the brine.

If a rotary drill bit penetrates the waste, radionuclides may be brought to the surface by four means. First, some quantity of cuttings that contain material intersected by the drill bit will be brought to the surface. Secondly, cavings that contain material eroded from the borehole wall by the circulating drill fluid may also be brought to the surface by that fluid. Thirdly, releases of radionuclides may occur if the repository contains fluids (brines or gas) at pressures higher than the pressure exerted by the drilling fluid. Finally, brine, as well as gas, may enter the borehole from the repository if the driller is unable to control the pressure within the well. The resulting fluid flow into the borehole may cause spalling of waste material into the borehole, which might then be carried to the surface by the drilling fluid. In addition to suspended (spalled) wastes, the brine that may flow to the surface may contain dissolved or suspended radionuclides depending on the extent of its contact with waste. Of the parameters included in the development of the estimated radionuclide release via the cutting, caving, and spalling mechanisms, the waste shear strength is indicated to have the most impact on the model results.

Direct brine release refers to the possibility that brine containing actinides may flow from waste panels up a borehole to the surface during drilling. It is conceptualized that direct brine release to the surface will not occur every time a borehole penetrates the waste panels; rather, it can occur only when two conditions are met. The first condition is the presence of a brine pathway; the second is that the pressure in the waste panels must be greater than the hydrostatic pressure of the column of drilling fluid. Quantities of brine flowing up shafts or exploratory boreholes are calculated in brine and gas flow (BRAGFLO), and the concentration of radionuclides in the brine determines the release.

FEP Sensitivity Conclusion

After evaluating the complement of FEPs used in the PA, it appears that the most sensitive Event is Human Intrusion since there is no release of radionuclides unless there is human intrusion. In addition, within the FEPs associated with Human Intrusion, the FEPs associated with Cuttings and Cavings are the most sensitive since they result in the preponderance of the potential releases. Thus, changes to the assumptions and inputs related to Human Intrusion would have the most effect on the PA.

The most sensitive Process is the chemical backfill addition (W10) because of the number of potential impacts to models and other FEPs affected if a chemical backfill was not included in the WIPP and the associated impact on the PA results if the inputs to the PA were adjusted accordingly. As outlined below, the chemical backfill reduces gas pressure and solubilities of the actinides and removes water. The chosen backfill is the engineered barrier Magnesium Oxide (MgO), which will consume any carbon dioxide generated by the waste.

It is also assumed that microbial activity neither produces nor consumes water, but the rate is dependent on the amount of liquid present in a computational cell for BRAGFLO. Hydration of MgO could significantly reduce the quantity of brine in the disposal panels, affecting the microbial gas generation rate. Effects of MgO on hydrogen (H_2) production from anoxic corrosion of steels and other Fe-base alloys in the repository and on room closure are less significant than the effects of MgO on conditions that will affect actinide solubilities.

MgO possesses inhibitory or even biocidal properties, but the absence of repository-specific experiments made it impossible to reduce the microbial gas-generation rates used in the PA. Biocides are often used for sterilization of solid materials; however, they become ineffective as the volume of the material(s) to be sterilized increases due to the difficulty of achieving uniform distribution of the biocide throughout these materials and the necessary contact between the biocide and the microbes. Although room closure will rupture the supersacks and disperse the MgO into the interstices among and within the ruptured waste containers, this will not ensure complete or uniform contact between MgO particles and microbes.

For room closure, the free air space was eliminated early in the calculations by unmitigated creep closure. Eventually, salt contacted the waste and deformed it according to the waste response model. At the same time, gas production pressurized the rooms. The coupled processes involved compression owing to the superincumbent rock counterbalanced by gas production. Rates of compression and gas production were both obtained from sampling of actual conditions in the WIPP. Thus, the room closure rate and final volume of the room were governed by salt creep modified by the structural response of the waste and by gas production. MgO was not considered in the room closure model, although MgO will absorb CO2 , which will result in reduced room pressure.

Emplacement of MgO in the disposal system will decrease solubilities of the actinide elements in TRU waste in any brine present in the repository after closure. MgO will decrease actinide solubilities by consuming essentially all CO2 that would be produced by microbial consumption of all CPR materials in TRU waste or waste containers in the repository. Although MgO will consume essentially all CO2, minute quantities (relative to the quantity that would be produced by microbial consumption of all CPR materials) will persist in the aqueous and gaseous phases. Consumption of CO2 will prevent acidification of brine, which could increase actinide solubilities. The geochemical functions that MgO must perform to decrease actinide solubilities and serve as an effective engineered barrier are to: 1) consume all CO2 that could be produced in the repository, and 2) buffer (control) the fugacity of CO2 (fCO2) so that the pH remains within ranges favorable from the standpoint of the speciation and solubilities of the actinides.

The effects of MgO carbonation (consumption of CO2) have been included in the PA by: 1) removing CO2 from the gaseous phase in BRAGFLO calculations, thereby reducing somewhat the predicted pressurization of the repository; and 2) using the values of fCO2 and pH established by reactions among MgO, brine, and aqueous or gaseous CO2 to calculate actinide solubilities. Reactions evaluated between CO2 and MgO result in the formation of brucite, hydromagnesite, magnesite, and calcite, the compounds that buffer the fugacity of CO2.

Another function that MgO will perform in the repository is to consume H_2O. MgO hydration (H_2O consumption) could consume H2O in quantities that are potentially significant from the standpoint of the long-term repository performance, particularly if the brine inflow does not 'fill' the panel. Potentially beneficial effects of MgO hydration include reductions in gas production, reductions in the pressurization caused by gas production, and reductions in the radioactive content in direct-brine and spallings releases. Ultimately, pH is used as both a calculated value and a known laboratory or field value in the PA. As an example of a model calculating the pH, the calculated pH increases as the BRAGFLO and other models account for the MgO absorbing CO_2. Conversely, the Nuclide Transport System Model (NUTS) program uses pH as an input and then dissolves the actinides until saturation is achieved or total inventory is reached. Oxidation states utilized in the PA were derived from laboratory studies and literature searches; they are also used as an input parameter to NUTS. However, MgO hydration is not presently included in the PA .

The most sensitive feature is the waste inventory (FEP W2) since the emplaced waste becomes a feature of the repository. Also, changes in some of the waste parameters such as shear strength, CPR content, iron content, and radionuclide distribution cause the greatest shifts in the PA results as presented in the complementary cumulative distribution functions (CCDF). The second most sensitive Feature is the brine repository (N2) coupled with the brine inflow (W40) since a brine reservoir of sufficient pressure is necessary for actinide release and transport.

IIIC. CONCEPTUAL MODELS

Conceptual Models are a set of qualitative assumptions used to describe a system or subsystem. At a minimum, these assumptions concern the geometry and dimensionality of the system, initial and boundary conditions, time dependence, and the nature of the relevant physical and chemical processes. There were 24 conceptual models created for the WIPP PA. As an example, one was the Disposal System Geometry model, which sets the modeled physical dimension and establishes the flow path (of water or brine) of the Salado formation, which are used by other models. *Attachment 2* identifies and provides a brief description of each conceptual model, along with the associated FEPs and computational models.

Computational Models

The forecast of the long-term behavior of the WIPP using conceptual models is achieved by a utilization of computational models. The computational model is the implementation of a mathematical model or a bounding model. (See explanation of mathematical model below.) The implementation may be through analytical or numerical means. Often, the analytical solution is numerically evaluated (for example, numerical integration or evaluation of complex functions); hence, both techniques are typically coded on the computer. Consequently, the computational model is often called a computer model. In the context of the WIPP, mathematical formulations have been developed to represent the processes at the WIPP site. The conceptual models provide the context within which these mathematical models must operate and define the processes they must characterize. The mathematical models are predictive in the sense that, once provided with known or assumed properties of the system and possible perturbations to the system, they predict the response of the system. Processes represented by these mathematical models include fluid flow, mechanical deformation, radionuclide transport in groundwater, and removal of waste through intruding boreholes.

An example of the computational model is “BRAGFLO” which uses input parameters to simulate brine and gas flow in the repository. This particular model is used in conceptual models such as “Direct Brine Release,” “Castile Brine Reservoir,” and “Repository Fluid Flow” that look at brine and gas flows in the repository. These are not the only conceptual models that use BRAGFLO, but they do serve as examples of how some computational models are incorporated into multiple conceptual models. (*Attachment 2* provides a listing of the computational models used for each conceptual model.) Additionally, BRAGFLO sets the “physical boundaries” of the disposal system for the other models.

There are two key analysis tools used in the PA. The first is the Monte Carlo Code, a technique that obtains distribution of approximate solutions to a problem by using statistical sampling techniques and computer simulations. For the PA, this method is used to evaluate distribution of the consequence results and thereby approximate the uncertainty in the results. In simple terms, this computer program takes the input information and statistically calculates how accurate the final results are. To accomplish this, the program may calculate results 10,000 times to ensure the results have a minimum of 95 percent probability of not exceeding EPA containment requirements. The second key analysis tool is the CCDFGF code, which assembles release estimates from all other components of the PA system to generate CCDFs of releases. This code only includes releases with a greater than a probability of 10^{-6}, because any result less than that would cause the resulting graph to be of such a scale as to be unreadable. The CCDF is mathematically, a complementary cumulative distribution function that is equal to one minus a cumulative distribution function. A cumulative distribution function is the sum (or integral) of the probability of those values or variables that are less than or equal to a specified value. Complementary cumulative distribution functions comprise a graphical display of the probability (the ordinate) that the value of the variable will be greater than a specified value (the abscissa). For the WIPP, the CCDF displays the probability that the 10,000-year cumulative radionuclide releases from the disposal system for the scenarios considered will exceed calculated values. Radionuclide releases are normalized as stipulated in 40 CFR 191, *Appendix A*, and the complementary cumulative distribution function is compared to the quantitative release limits specified in 40 CFR 191.13(a). Simply put, this program takes the calculated radionuclide release normalized information from the computational models and calculates the probability that the release will exceed the EPA radionuclide limit. *Figure 2* provides the summed CCDF release curve compared to the EPA limits. The EPA limit curve shows that the normalized limit of one (10^0) corresponds to a 10 percent probability of being exceeded and a one in 1000 (10^{-3}) probability of exceeding 10 times the limit.

The results of the PA can be altered by changing the values of measured inputs or by using different assumptions or by changing the boundary conditions. A change in input values reflects the results of new data and improves the accuracy of the PA. A change in assumptions generally reflects an acceptance by the modelers that the original assumptions were too unrealistic. For example, within the repository portion of the BRAGFLO model, fluid flow in a single panel is treated as if it was a single void (that is, pillars are omitted). Since this assumption is known to differ from actual conditions in the repository, the effect is conservative and results in the assumption of a higher flow rate and greater contact of the brine with the waste than may actually occur. If this particular area had been modeled using the actual repository configuration, the CCDF curve would move away from the limits for this particular model. Assumptions related to gas generation and consequent reactions with MgO also would have a significant impact on the CCDF curve. The assumption that there is less production of CO_2 as a result of either less brine availability from the Castile formation or a microbe mix that produces more CH_4 than CO_2 would also result in the CCDF curve moving away from the limits.

A change in boundary conditions would equate to a change in the regulator mandated requirements such as the allowable time period for the effectiveness of the passive institutional barriers or the requirement that all organic carbon in the WIPP will convert to CO_2 or the exposure standard. These changes may or may not be supported by new data.

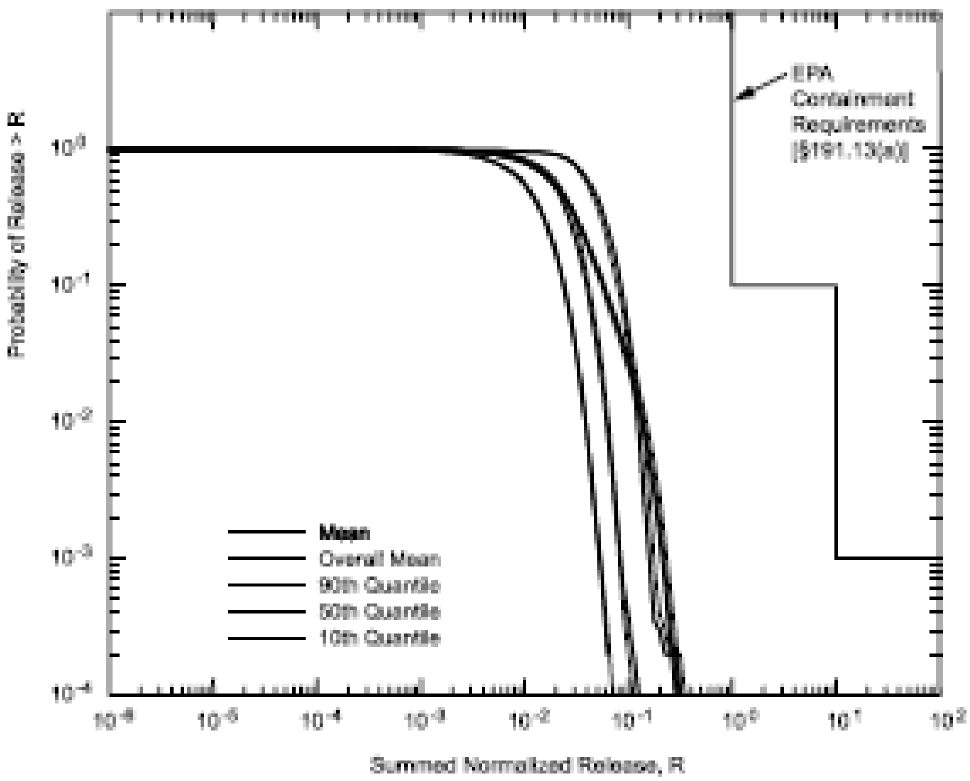

Figure 2. CCDF (from CRA 2004)

IIID. PA MODELS

Input Data

All computational models must have information in order to produce results. Such information is typically referred to as input data or model parameters and serves to describe the expected condition, enabling the computer to calculate results. Input parameters are measured, calculated, estimated, or stipulated by others. Results from the models using inputs based on information gathered from actual conditions around the WIPP—such as the use of data gathered from on-site monitoring wells or on recognized standard scientific constants—are most representative of actual conditions. Inputs whose calculations are based on measurements taken under conditions or at locations that are similar to the WIPP result in more uncertain model outputs. The other approach involves using parameter ranges such as the permeability parameter or the waste shear strength parameter whose estimates are based on literature reviews and results of tests on a range of materials and conditions that do not necessarily match expected conditions in the WIPP post closure.

Because changes in the permeability of the DRZ after closure have not been measured in the field, estimates to determine probable range of permeability for specific areas in the WIPP were based on laboratory tests. However, the application of the permeability estimate varied depending on the model. In some models, permeability was input as a range from minimum to maximum. In other models, it was input as a range bounding the worst-case scenario, such as the conservative permeability range used in the DRZ model. (Due to the constantly changing nature of the DRZ because of salt creep, the EPA required that a worst-case range be used in the model.)

The waste shear strength parameter is a key input to the models that predict the potential release of radionuclides due to cuttings and cavings that result from drilling into the WIPP. The value of waste shear strength parameter is dependent upon many factors, including principally, the composition of the waste, the density of the waste, and the presence of brine in the repository. Since there were no measurements available on shear strengths of different waste forms under postulated conditions that might occur in the WIPP, the lower range of shear strengths was estimated in the initial PA to be as low as bay muds (almost zero). As a result, the estimate of releases via cuttings and cavings is not considered to be at all representative of actual conditions.

Inputs stipulated by others include those required by regulation or specifically by the EPA. For example, intrusion into the waste by a borehole was required by 40 CFR 194.33. The limit of 100 years for active institutional controls is also established in 40 CFR 194.33. Another example is the permeability range for the DRZ specified by the EPA, which was discussed in Section III.B above.

Model Assumptions

Assumptions are closely related to and sometimes the same as input data. Though assumptions are used for various reasons, assumptions are particularly useful in making a model easier to calculate. For example, fluid flow in the disposal area is modeled as a large open area. In truth, the area has multiple walls and columns that would actually restrict flow. By assuming it is one large area, the model overestimates the flow and is consequently referred to as a conservative model. The Castile reservoir is considered a pressurized system, and with the assumption that the disposal area is completely open, the brine flow is allowed to progress unimpeded to allow for maximum contact with the waste. Additionally, this process does not include flow constrictions from future salt creep in order to allow maximum release of waste. Anytime an assumption is used to make calculations easier, the assumption must make the model conservative. Other assumptions are included to ensure the disposal of materials is safe. In the regulations, the PA is required to assume that a borehole penetrates the disposed waste when someone is exploring for oil or gas. Once again, this is considered conservative because regulations do not allow any probability that the event will not occur even though it is unknown if anyone will ever drill into the waste. In the PA, the terms E1, E2, and E1E2 are used, describing the intrusion scenarios. The events are defined as follows:

E1 – Intrusion event in which a borehole penetrates the panel and a Castile brine reservoir;

E2 – Intrusion event in which a borehole penetrates the repository but not a Castile brine reservoir; and

E1E2 – Intrusion event in which at least one E1 borehole and one other borehole (E2) penetrate a disposal panel. ***Figure 3*** represents the EIE2 scenario.

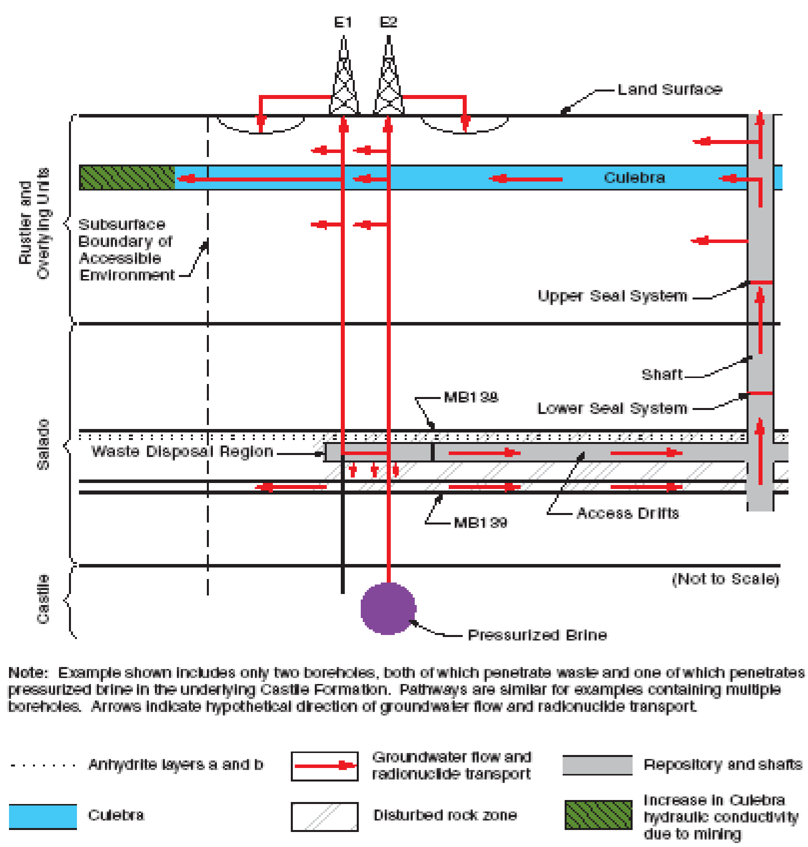

Figure 3. **E1E2 Human Intrusion Scenario** (from CRA 2004)

By using the E1, E2, and E1E2 intrusion scenarios, multiple intrusions into the controlled area to represent the three scenarios must occur. On the probability of hitting the brine reservoir over 10,000 years, the original CCA listed a probability of 0.08. EPA did not agree and specified a probability range of 0.01 to 0.60, which added significant conservatism to this variable..

Assumptions can create discussions regarding both the realism and the accuracy of the model results. Such discussions typically result from inconsistent application of assumptions across all of the models. For instance, MgO is used in the disposal cells, and it absorbs certain gases and water. The models that represent gases in the repository incorporate the absorption into the results, but the models associated with water or brine do not consider any absorption by MgO. While the models associated with water or brine are more conservative by not considering absorption by MgO, the inconsistency of the assumptions detracts from the scientific validity of the PA. Another example is the assumption in the BRAGFLO model regarding panel geometry and contents that do not represent the actual conditions.

One assumption used in various models (conceptual and computational) that was not fully explained is the rate of brine infiltration into a panel after closure. It appears the panel was instantly filled with brine in some cases and in other cases, it appeared to be a slow infusion combined with gas-generation parameters. There is a discussion in Chapter 6 of the CRA that discusses the hydraulic heads for the initial conditions, but it does not discuss the impact as the model simulate changes.

Finally, the DOE identified the following assumptions used in the PA (Table 6-30, Chapter 6, CCA) that, while considered to be conservative, are not supported by field or laboratory data:

- Long-term flow up plugged and abandoned boreholes is modeled as if all intrusions occur into a down-dip (southern) panel.
- Pillars, individual drifts, and rooms are not modeled for long-term performance, and containers provide no barrier to fluid flow.
- Brine in the repository will contain a uniform mixture of dissolved species. All actinides have instant access to all repository brine.
- Radionuclide dissolution to solubility limits is instantaneous.
- Radionuclides are not retarded by shaft seals.
- Shaft concrete components of the lower shaft are modeled as if they degrade after emplacement.
- The permeability of the DRZ is modeled with both a low value similar to intact halite and the higher value representing a fractured material.

- The Los Medaños member of the Rustler, Tamarisk, and Forty-niner are assumed to be impermeable.
- Sorption of actinides in the borehole is not modeled.
- Sorption occurs on dolomite in the matrix. Sorption on clays present in the Culebra is not modeled.
- Particle waste shear is based on properties of marine clays, considered a worst case.
- The concentrations of actinides in liquid moving up the borehole in the E1E2 scenario assumes homogenous mixing within the panel.
- For all direct releases to the surface and the E1E2 source term to the Culebra, any actinides that enter the borehole are assumed to reach the surface or the Culebra.
- A hemispherical geometry with one-dimensional spherical symmetry defines the flow field and cavity in the waste.
- Tensile strength, based on completely degraded waste surrogates, is felt to represent extreme, low-end tensile strengths because it does not account for several strengthening mechanisms.
- Shape factor is 0.1, corresponding to particles that are easier to fluidize and entrain in the flow.
- It is assumed that retardation does not occur in the Salado.
- Depletion of actinides in parts of the repository that have been penetrated by boreholes is not accounted for in calculating releases from subsequent intrusions at such locations.
- Hydraulically significant fractures are assumed to be present everywhere in the Culebra.

There was no discussion found that alluded to the impact of these unsupported assumptions or inputs on the results of the PA, nor was there a discussion as to whether any of the assumptions resulted in changes to the repository design or operational approaches.

Major Variables

Our evaluation of the PA indicates that the six major variables that have the most impact the EPA compliance requirements are:

1. Probability of human intrusion;
2. Composition and quantity of the TRU waste, particularly the curie content;
3. Brine migration or inflow into the waste disposal rooms—timing and quantity;

4. Changes in atmospheric chemistry in the filled rooms and panels—reduction in the concentration of oxygen;
5. Types and rates of biological and chemical reactions that occur in filled rooms and panels; and
6. Natural and engineered barriers (in particular, the use of Magnesium Oxide).

Discussions on those variables are provided in the following sections.

Human Intrusion Scenarios

EPA has mandated that the PA must include the scenario of one or more boreholes into the repository and one or more boreholes through the repository (waste disposal area) into the Castile formation. This requirement appears to be based on the assumption that future generations (starting 100 years after closure) will have suffered a "widespread societal loss of knowledge regarding radioactive waste" (40 CFR 191, Appendix C). The assumption regarding loss of knowledge is arguably unrealistic. It is difficult to imagine a scenario in which future generations are not knowledgeable of radioactive wastes—particularly with emphasis on the WIPP document repository program—yet continue to have the know-how to drill thousands of feet into the ground; or to assume that such drilling activities would be unregulated by federal or state agencies that have a long-term "institutional memory." It is also contrary to the assumption indicated in 40 CFR 194 that passive institutional controls will be effective for several hundred years. Nevertheless, the choices are either to assume there is human intrusion; or to assume there is no human intrusion. Since throughout history, mankind has apparently explored every "unknown" encountered, the assumption that there will be human intrusion is realistic. The assumptions (based on historical data) of the probability and frequency of boreholes being drilled into or through the repository, however, are overly conservative.

Composition and Quantity of TRU Wastes, Particularly Curie Limits

The bounding condition for the PA for the WIPP with respect to waste inventory is the maximum allowable waste volume (6.2 million cubic feet) rather than maximum allowable curies. The curie limit established by the LWA appears to have been based on a conservative estimate of the curies of TRU waste in the inventory at that time (1990s) as well as on what was expected to be generated during the life of the WIPP. Since the amount of curies does not affect the CCDF, the question is whether an increase in waste volume (m^3) would otherwise cause EPA exposure standards to be violated.

Another issue regarding waste characterization is the accuracy of the estimates of mass of CPR materials emplaced in WIPP. Those estimates are used to determine the amount of MgO to be added so their accuracy is the first critical factor in that estimate. Related to that is the question as to whether the trend towards super-compaction of the CH TRU wastes will result in more CPR materials in WIPP than authorized (Table 4.11, Chapter 4, CRA). An analysis performed by DOE in 2002 indicated that even if the CPR limit was exceeded, there would be sufficient MgO to offset the potential carbon dioxide production. However, the PA in the CRA did not consider quantities of CRP beyond the allowed limit.

A third issue is the assumption used for the percentage of liquids in the wastes. The Waste Acceptance Criteria limit the amount of liquids in the waste containers to ≤ 1% by volume. The PA uses an assumption of ≤ 2% liquid by volume. No reason is provided for the use of the higher percent of liquids in the PA.

Brine Migration and Inflow

Brine migration and inflow is a critical parameter for the PA because the major chemical and microbiological actions postulated to occur after the waste is emplaced in the WIPP require the presence of substantial amounts of water (brine in the instance of the WIPP). Two possible sources of brine are postulated for the PA: 1) brine inflow from the surrounding salt and/or 2) brine inflow from a penetration of the Castile formation. As discussed above, the assumed probability of penetrating a brine reservoir with sufficient volume and under sufficient pressure to flood a waste panel does not reflect that actual data of brine reservoir conditions in the Castile formation.

In addition to the question as to whether there will be brine in the first place, the rate and timing of brine infiltration into a panel after closure is not clearly explained in the PA. In fact, there are contradictions in the text as to whether the brine inflow will happen as soon as 100 years after closure or as late as 350 years after closure (2). It appears that the panel was instantly filled with brine upon closure in some cases and in other cases it appeared to be a slow infusion combined with gas generation parameters. The difference is significant. If the panels fill instantly upon closure, then microbial gas generation could start fairly quickly and enough gas could be generated to prevent complete closure of the void spaces in the panels, which would facilitate brine inflow and outflow. If there is little or no brine inflow from the surrounding formation, then it is very probable there will be minimal void space and a much lower rate of brine flow into, across, and through the wastes, and thus, a much lower and slower rate of gas generation. The probability of hitting a brine reservoir and the timing of brine inflow are key assumptions with major effects on the need for MgO and should be given high priority for better definition. While probably minor, the impact of the absorption or hydration of brine by MgO on the brine availability to react or support reactions with the waste should also be included in the PA.

Changes in Atmospheric Conditions in the Filled Panels

The critical assumption here is the length of time necessary to deplete the oxygen content in the closed panels to allow the biological gas generation to proceed and create the CO_2 of concern relative to actinide solubility. However, a conflicting operating issue is the assumption that a methane explosion might occur in a closed panel. If methane is generated, the atmosphere in the panel would still have to retain a high percentage of oxygen for a number of years to result in either deflagration or explosion. However, generation of methane requires an anoxic environment as well as sufficient brine/water to sustain the microbes. One possibility is that the containers of waste are already anoxic and there would be enough water in the containers to produce sufficient methane to develop an explosive mixture in the remaining air in the panel. This is highly unlikely given that there is one percent or less liquid in the containers. Another possibility would require the assumption that the brine inflow occurred relatively soon after panel closure and filled the waste containers. Again, since most of the waste containers are HEPA filter vented, it is doubtful the brine would be able to flow through the vents to support gas production in the quantities necessary to support the postulated methane explosion used to develop the panel closure system.

Types and Rates of Chemical and Biological Reactions

The driving force for this variable appears to be primarily the probability and timing of the brine inflow, creating either an inundated or a very humid environment around the waste. If/when that occurs, the next question concerns the effect of the presence of iron on the reactions. Another major question is the percentage of CO_2 produced versus the percentage of CH_4 produced. The PA is based on the EPA-mandated requirement that 100 percent of available carbon in the waste will be converted to CO_2, which appears to be questionable due to the composition of the carbon containing waste, the amount and composition of the brine, the lack of movement of the brine, and the assumption that sufficient sulfates will be released into the brine from the marker beds. Unfortunately, there have been no research or tests (through 2004) that quantify the impact of MgO on chemical microbial actions that might occur in the wastes after closure; so the assumptions regarding gas generation are not well supported by science. Finally, there is no discussion of the reduced solubility of high-fired plutonium in the waste on the estimates of the solubility of plutonium.

Natural and Engineered Barriers

There were four engineered barriers considered in the CCA:

1. Panel closure systems
2. Shaft seals
3. Backfill around the waste
4. Borehole plugs

The proposed backfill around the waste was MgO. PA results indicate that none of the proposed engineered barriers are necessary to meet the EPA requirements for waste characteristics and limits used to bound the PA. This includes MgO, which while the most sensitive variable, is still not necessary for EPA compliance. Interestingly, the LWA mandated that all four of the engineered barriers proposed by DOE should be considered as engineered barriers; but EPA only accepted backfill around the waste as an applicable engineered barrier. This differentiation is immaterial, since the PA results show none of the engineered barriers are necessary for compliance with the 10,000-year release and exposure requirements.

Creditability of Data, Assumptions and Inputs Used in the PA

As summarized above, many instances were identified where assumptions or inputs used for the PA were not uniformly applied or were not well substantiated. Some of these instances have a major impact on the PA, including the effects of MgO on waste reactions and rate of brine inflow to the repository. When assumptions or inputs are not applied uniformly, or when known (measured) effects are not included, the result may be a more conservative, but not necessarily realistic, forecast. While counter to best science concepts and principles, it does error favorably toward future public protection; though at both a safety (forecasted loss of life during WIPP operations) and monetary expense to the present population.

IV. CONCLUSIONS

The PA represents an admirable effort to predict the future and protect future generations from the remote possibility of the release of radioactive contamination from the WIPP. However, it was noted that there are numerous instances of inconsistency in both value and use of assumptions. Assumptions should be consistent with one another as well as with existing information within the context of the given purpose. In addition, scientifically proven effects should always be included rather than assumed to not occur, as long as mandated safety factors (conservatism) are maintained in the modeling effort. Failure to ensure this is the case drastically reduces the creditability of the PA (unrealistic assumptions equal unrealistic results). More importantly, such inconsistencies may have resulted in the application of restrictive operating conditions, which can limit the WIPP's benefits to society, unnecessarily waste taxpayers' money, and increase the risk for accident or injury to the operational workforce.

The human intrusion scenarios have the most impact on the possibility of release of radioactivity to the accessible environment over the 10,000 years after WIPP closure. Since the major component of radioactivity release is via cuttings and cavings, it appears that the addition of MgO to reduce radioactivity releases via brine flow is not well justified, a point further reinforced by the highly conservative (and unsubstantiated) assumptions made with respect to brine inflow and microbial activity.

Models that are overly conservative have an impact on operations and increase operational cost. Two such examples are the assumptions and resulting requirements for shaft closure or panel closure and waste moisture content. The shaft closure uses multiple materials placed in layers to close the shafts, and the lower layer of concrete is assumed to begin to degrade immediately after placement, which is only likely if the concurrent assumption of immediate brine inflow to the repository upon closure actually occurs. The other overly conservative assumption for the shaft closure is that the materials will allow radionuclides to pass through. If more realistic assumptions were used, the shafts may be closed using fewer layers, which would reduce costs as well as worker health and safety risk, and it would still be protective of the environment. For panel closure, the design is a concrete wall that is 7.9 meters thick and an explosion wall constructed of solid block that is 3.7 meters thick. Between the two walls the drift is open for 9.1 meters. The designs are based on the possibility that hydrogen or methane can accumulate in an explosive mixture and an ignition source is available to cause the deflagration. A simpler closure approach may be to backfill the complete 20.7 meter drift with salt. Based on the summary information presented in the CRA, it cannot be determined if both closures could be scaled back and still achieve the desired effect. It does appear however, that the two closures are overly conservative[6].

On the waste moisture content, the waste acceptance criteria define the maximum amount of moisture allowed in the waste. In the models that include water, the MgO, as discussed above, is not utilized in the calculations. Although realizing that the industry standard is typically a 1 percent liquid content limit, WIPP is unique in the use of MgO. If more realistic assumptions were used, the allowed moisture content could potentially be increased without impacting the PA results, since there is excess MgO required by EPA. This would reduce potential exposures to waste treatment workers, and waste generators would spend less money to decrease moisture content.

V. RECOMMENDATIONS

Based upon our assessment of the structure, sensitivity, limiting conditions, inputs, and assumptions of the PA, it is recommended that DOE concentrate/accelerate its efforts to:

1. Improve the estimate for the probability of the presence of a brine reservoir that would result in brine inflow into the repository.
2. Acquire actual data from repository operations and conditions to reduce uncertainties associated with the following variables, in order of priority:
   a. Changes in conditions after a panel is closed, particularly with respect to brine inflow, room closure (salt creep) and atmospheric chemistry. As much effort as possible should be placed

on providing very strong and reasoned support for the contention (assumption) that there is very low probability of brine inflow from the Salado Formation; and that any brine inflow from the Castile Formation should be modeled as flow through porous media.

b. The speed and extent of waste reactions and resulting products associated with both super-compacted wastes and high-fired wastes.

2. Perform the PA by inputting increasing volumes of TRU waste in order to determine the upper volumetric limits (between CH and RH wastes) that could be disposed in the WIPP and still maintain compliance with EPA standards—since it is expected that TRU waste will continue to be generated and require disposal after WIPP has reached it volumetric limit.
3. Run a fully documented and refereed PA using the assumption there will be no further additions of MgO. If the results of that run, performed in full compliance with the EPA requirements, show that MgO is not necessary for compliance with the EPA standards, then DOE could use that run as the basis for a petition for a rule-making, calling for EPA to delete the requirement for the use of MgO as an engineered barrier.
4. Conduct a thorough review of the PA, and apply all assumptions and inputs uniformly.

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Attachment 1

Retained FEPs of Models

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
N1	**Stratigraphy**	The stratigraphy and geology of the region was included as an undisturbed performance characteristic. The thickness and lateral extent were inputs.	▪ **Disposal System** ▪ **Culebra Geometry** ▪ **Impure Halite** ▪ ***Considered in* Transport of Dissolved Actinides in the Culebra**
N2	**Brine Reservoir**	The distribution and characteristics of a pressurized brine reservoir was included as a disturbed performance characteristic.	▪ **Castile Brine Reservoir**
N8	**Formation of Fractures**	Repository induced fractures are possible and this has been retained as an undisturbed performance characteristic	▪ **Disturbed Rock Zone (DRZ)**
N9	**Changes in Fracture Properties**	Changes in fractures near the repository are possible and therefore have been retained as an undisturbed performance characteristic.	▪ **DRZ**
N12	**Seismic Activity**	Seismic activity in the Central Basin Platform may be associated with natural earthquakes, but there are also indications that this activity occurs in association with oil-field activities such as fluid injection. This was included as an undisturbed performance characteristic.	▪ **DRZ**
N16	**Shallow Dissolution, including Lateral Dissolution**	A distinction has been drawn between *Shallow Dissolution*, involving circulation of groundwater and mineral dissolution, in the Rustler and at the top of the Salado in the region of the WIPP; and deep dissolution taking place in the Castile and the base of the Salado. Dissolution will initially enhance porosities, but continued dissolution may lead to compaction of the affected units with a consequent reduction in porosity. Compaction may result in fracturing of overlying brittle units and increased permeability. Extensive dissolution may create cavities (karst) and result in the total collapse of overlying units. Retained as an undisturbed performance characteristic.	▪ **Units Above the Salado**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
N23	**Saturated Groundwater Flow**	Potential water flow was included as an undisturbed performance characteristic.	▪ **Disposal System** ▪ **Repository Fluid Flow** ▪ **Salado** ▪ **Salado Interbeds** ▪ **Units Above the Salado** ▪ ***Considered in* Transport of Dissolved Actinides in the Culebra**
N24	**Unsaturated Groundwater Flow**	Potential water flow was included as an undisturbed performance characteristic.	▪ **Disposal System** ▪ **Repository Fluid Flow** ▪ **Shafts and Shaft Seals** ▪ **Units Above the Salado** ▪ ***Considered in* Transport of Dissolved Actinides in the Culebra**
N25	**Fracture Flow**	Water flow pathways were included as an undisturbed performance characteristic.	▪ **Actinide Transport in the Salado** ▪ **Units Above the Salado**
N27	**Effects of Preferential Pathways**	Water flow pathways were included as an undisturbed performance characteristic. The estimates of transmissivity and aquifer thickness were used for the pathways. This has been retained as an undisturbed performance characteristic.	▪ **Units Above the Salado**
N33	**Groundwater Geochemistry**	Salinity is the most important aspect in terms of retardation and colloid stability. Waters in the Castile and Salado are at or near halite saturation. Above the Salado, groundwaters	▪ **Transport of Dissolved Actinides in the Culebra**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		are also relatively saline, and groundwater quality is poor in all of the permeable units. Waters from the Culebra vary spatially in salinity and chemistry. They range from saline sodium chloride-rich waters to brackish calcium sulfate-rich waters. In addition, a range of magnesium to calcium ratios has been observed, and some waters reflect the influence of potash mining activities, having elevated potassium to sodium ratios. Waters from the Santa Rosa are generally of better quality than any of those from the Rustler. Salado and Castile brine geochemistry is accounted for in PA calculations of the actinide source term. Culebra brine geochemistry is accounted for in the retardation factors used in PA calculations of actinide transport. This has been retained as an undisturbed performance characteristic.	
N39	**Physiography**	The physiography, geomorphology, and topography of the region were used in the set up of the model. This has been retained as an undisturbed performance characteristic.	▪ **Disposal System**
N53	**Groundwater Discharge**	The groundwater basin is governed by flow from areas where the water table is high to areas where the water table is low. The height of the water table is governed by the amount of *Groundwater Recharge* reaching the water table, which in turn is a function of the vertical hydraulic conductivity and the partitioning of precipitation between evapotranspiration, runoff, and *Infiltration*. Flow within the Rustler is also governed by the amount of *Groundwater Discharge* that takes place from the basin. In the region around the WIPP, the principal discharge areas are along Nash Draw and the Pecos River. Groundwater flow modeling accounts for infiltration, recharge, and discharge. This has been retained as an undisturbed performance characteristic.	▪ **Culebra Geometry** ▪ **Units Above the Salado**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
N54	**Groundwater Recharge**	The groundwater basin is governed by flow from areas where the water table is high to areas where the water table is low. The height of the water table is governed by the amount of *Groundwater Recharge* reaching the water table, which in turn is a function of the vertical hydraulic conductivity and the partitioning of precipitation between evapotranspiration, runoff, and *Infiltration*. Flow within the Rustler is also governed by the amount of *Groundwater Discharge* that takes place from the basin. In the region around the WIPP, the principal discharge areas are along Nash Draw and the Pecos River. Groundwater flow modeling accounts for infiltration, recharge, and discharge. This has been retained as an undisturbed performance characteristic.	▪ **Culebra Geometry** ▪ **Units Above the Salado**
N55	**Infiltration**	The groundwater basin is governed by flow from areas where the water table is high to areas where the water table is low. The height of the water table is governed by the amount of *Groundwater Recharge* reaching the water table, which in turn is a function of the vertical hydraulic conductivity and the partitioning of precipitation between evapotranspiration, runoff, and *Infiltration*. Flow within the Rustler is also governed by the amount of *Groundwater Discharge* that takes place from the basin. In the region around the WIPP, the principal discharge areas are along Nash Draw and the Pecos River. Groundwater flow modeling accounts for infiltration, recharge, and discharge. This has been retained as an undisturbed performance characteristic.	▪ **Units Above the Salado**
N56	**Changes in Groundwater Recharge and Discharge**	Changes in recharge may affect groundwater flow and radionuclide transport in units such as the Culebra and Magenta dolomites. Changes in the surface environment driven by natural climate change are expected to occur over the next 10,000 years (see FEPs N59 to	▪ **Units Above the Salado**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		N61). Groundwater basin modeling indicates that a change in recharge will affect the height of the water table in the area of the WIPP, and that this will in turn affect the direction and rate of groundwater flow. This has been retained as an undisturbed performance characteristic.	
N59	**Precipitation**	Precipitation in the region is low (about 33 cm (13 in.) per year) and temperatures are moderate with a mean annual temperature of about 63°F (17°C). *Precipitation* and *Temperature* are important controls on the amount of recharge that reaches the groundwater system and are accounted for in PA calculations by use of a sampled parameter for scaling flow velocity in the Culebra. This has been retained as an undisturbed performance characteristic.	▪ **Units Above the Salado** ▪ **Climate Change**
N60	**Temperature**	Precipitation in the region is low (about 33 cm (13 in.) per year) and temperatures are moderate with a mean annual temperature of about 63°F (17°C). *Precipitation* and *Temperature* are important controls on the amount of recharge that reaches the groundwater system and are accounted for in PA calculations by use of a sampled parameter for scaling flow velocity in the Culebra. This has been retained as an undisturbed performance characteristic.	▪ **Units Above the Salado** ▪ **Climate Change**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
N71	**Microbes**	Due to their large sizes, microbial cells as colloidal particles will be rapidly filtered out in the Culebra formation. This has been retained as an undisturbed performance characteristic for colloidal effects and gas generation.	▪ **Colloidal Actinide Source Term**
W1	**Disposal Geometry**	Based upon the expected configuration of waste materials in the disposal panel.	▪ **Shafts and Shaft Seals**
W2	**Waste Inventory**	The waste inventory is accounted for in PA calculations in deriving the dissolved actinide source term and gas generation rates. The distribution of contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste within the repository leads to room scale heterogeneity of the waste forms, which is accounted for in PA calculations when considering the potential activity of waste material encountered during inadvertent borehole intrusion. This has been retained as an undisturbed performance characteristic.	▪ **Gas Generation** ▪ **Dissolved Actinide Source Term**
W3	**Heterogeneity of Waste Forms**	The distribution of contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste within the repository leads to room scale heterogeneity of the waste forms, which is accounted for in PA calculations when considering the potential activity of waste material encountered during inadvertent borehole intrusion. This has been retained as a disturbed performance characteristic.	▪ **Chemical Conditions** ▪ **Dissolved Actinide Source Term**
W5	**Container Material Inventory**	Used in the estimation of gas generation rates.	▪ **Gas Generation**
W6	**Seal Geometry**	The representation of the seal system in BRAGFLO and the permeabilities assigned to the seal materials.	▪ **Shafts and Shaft Seals**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
W10	**Backfill Chemical Composition**	A chemical backfill is added to the disposal room to buffer the chemical environment.	▪ **Chemical Conditions**
W12	**Radionuclide Decay and In-Growth**	Utilized to calculate the inventory of waste at a particular time in a model.	▪ **Actinide Transport in the Salado**
W18	**Disturbed Rock Zone (DRZ)**	Construction of the repository has caused local *excavation-induced changes in stress* in the surrounding rock. This has led to failure of intact rock around the opening, creating a DRZ of fractures. On completion of the WIPP excavation, the extent of the induced stress field perturbation will be sufficient to have caused dilation and fracturing in the anhydrite layers a and b, MB139, and, possibly, MB138. The creation of the DRZ around the excavation and the disturbance of the anhydrite layers and marker beds will alter the permeability and effective porosity of the rock around the repository, providing enhanced pathways for flow of gas and brine between the waste-filled rooms and nearby interbeds. The DRZ around repository shafts could provide pathways for flow from the repository to hydraulically conductive units above the repository horizon. The effectiveness of long-term shaft seals is dependent upon the seals providing sufficient backstress for salt creep to heal the DRZ around them, so that connected flow paths out of the repository horizon will cease to exist. This has been retained as an undisturbed performance characteristic.	▪ **Shafts and Shaft Seals** ▪ **DRZ**
W19	**Excavation Induced Changes in Stress**	Construction of the repository has caused local *excavation-induced changes in stress* in the surrounding rock. This has led to failure of intact rock around the opening, creating a DRZ of fractures. On completion of the WIPP excavation, the extent of the induced stress	▪ **Creep Closure**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		field perturbation will be sufficient to have caused dilation and fracturing in the anhydrite layers a and b, MB139, and, possibly, MB138. The creation of the DRZ around the excavation and the disturbance of the anhydrite layers and marker beds will alter the permeability and effective porosity of rock around the repository, providing enhanced pathways for flow of gas and brine between waste-filled rooms and the nearby interbeds. The DRZ around repository shafts could provide pathways for flow from the repository to hydraulically conductive units above the repository horizon. The effectiveness of long-term shaft seals is dependent upon the seals providing sufficient backstress for salt creep to heal the DRZ around them, so connected flow paths out of the repository horizon will cease to exist. This has been retained as an undisturbed performance characteristic.	
W20	**Salt Creep**	*Salt Creep* will lead to *Changes in the Stress Field*, compaction of the waste and containers, and consolidation of the long-term components of the sealing system. It will also tend to close fractures in the DRZ, leading to reductions in porosity and permeability, increases in pore fluid pressure, and reductions in fluid flow rates in the repository. The long-term repository seal system relies on the consolidation of the crushed-salt seal material and healing of the DRZ around the seals to achieve a low permeability under stresses induced by salt creep. This has been retained as an undisturbed performance characteristic.	▪ **Creep Closure** ▪ **Repository Fluid Flow** ▪ **Shafts and Shaft Seals**
W21	**Changes in the Stress Field**	*Salt Creep* will lead to *Changes in the Stress Field*, compaction of the waste and containers, and consolidation of the long-term components of the sealing system. It will also tend to close fractures in the DRZ, leading to reductions in porosity and permeability, increases in pore fluid pressure, and reductions in fluid flow rates in the repository.	▪ **Creep Closure**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		The long-term repository seal system relies on the consolidation of the crushed-salt seal material and healing of the DRZ around the seals to achieve a low permeability under stresses induced by salt creep. This has been retained as an undisturbed performance characteristic.	
W22	**Roof Falls**	Instability of the DRZ could to lead to localized *Roof Falls* in the first few hundred years. If instability of the DRZ causes roof falls, development of the DRZ may be sufficient to disrupt the anhydrite layers above the repository, which may create a zone of rock containing anhydrite extending from the interbeds toward a waste-filled room. Fracture development is most likely to be induced as the rock stress and strain distributions evolve because of creep. In the long term, the effects of roof falls in the repository are likely to be minor because Salt *Creep* will reduce the void space and the potential for *Roof Falls* as well as leading to healing of any roof material that has fallen into the rooms. However, because of uncertainty in the process by which the disposal room DRZ heals, the flow model used in the PA assumes that a higher permeability zone remains for the long term. Thus, potential effects of *Roof Falls* on flow paths are accounted for in PA calculations through appropriate ranges of the parameters describing the DRZ. This has been retained as an undisturbed performance characteristic.	▪ **DRZ**
W25	**Disruption Due to Gas Effects**	The mechanical effects of gas generation, including the slowing of creep closure of the repository due to gas *Pressurization*, and the fracturing of interbeds in the Salado through *Disruption Due to Gas Effects* are accounted for. This has been retained as an undisturbed performance characteristic.	▪ **Salado Interbeds**
W26	**Pressurization**	The mechanical effects of gas generation, including the slowing of creep closure of the repository due to gas *Pressurization*, and the	▪ **Creep Closure**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		fracturing of interbeds in the Salado through *Disruption Due to Gas Effects* are accounted for. This has been retained as an undisturbed performance characteristic.	
W27	**Gas Explosions**	Explosive gas mixtures could collect in the head space above the waste in a closed panel. The most explosive gas mixture potentially generated will be a mixture of hydrogen, methane, and oxygen which will convert to CO_2 and water on ignition. This means that there is little likelihood of a *Gas Explosion* in the long term, because the rooms and panels are expected to become anoxic and oxygen depleted. Compaction through salt creep will also greatly reduce any void space in which the gas can accumulate. Analysis indicates that the most explosive mixture of hydrogen, methane, and oxygen will be present in the void space approximately 20 years after panel-closure emplacement. This possibility of an explosion prior to the occurrence of anoxic conditions is considered in the design of the operational panel closure. The effect of such an explosion on the DRZ is expected to be no more severe than a *Roof Fall* which is accounted for. This has been retained as an undisturbed performance characteristic.	▪ **DRZ**
W32	**Consolidation of Waste**	*Consolidation of Waste* is accounted for in PA calculations in the modeling of creep closure of the disposal room. This has been retained as an undisturbed performance characteristic.	▪ **Creep Closure**
W36	**Consolidation of Seals**	*Consolidation of Seals* are accounted for in PA calculations through the permeability range assumed for the seal system. This has been retained as an undisturbed performance characteristic.	▪ **Shafts and Shaft Seals**
W37	**Mechanical Degradation of Seals**	*Mechanical Degradation of Seals* is accounted for in PA calculations through the permeability range assumed for the seal system. This has been retained as an	▪ **Shafts and Shaft Seals**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		undisturbed performance characteristic.	
W39	**Underground Boreholes**	Any boreholes that remain unsealed will connect the repository to anhydrite interbeds within the Salado, and thus provide potential pathways for radionuclide transport. PA calculations account for fluid flow to and from the interbeds by assuming that the DRZ has a permanently enhanced permeability that allows flow of repository brines into specific anhydrite layers and interbeds. This treatment is also considered to account for the effects of any unsealed boreholes. This has been retained as an undisturbed performance characteristic.	▪ **DRZ**
W40	**Brine Inflow**	*Brine Inflow* to the repository may occur through the DRZ, impure halite, anhydrite layers, or clay layers. Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Two-phase flow of brine and gas in the repository and the Salado is accounted for. This has been retained as an undisturbed performance characteristic.	▪ **Gas Generation** ▪ **Shafts and Shaft Seals**
W41	**Wicking**	Capillary rise (or *Wicking*) is a potential mechanism for liquid migration through unsaturated zones in the repository. Capillary rise in the waste material could affect gas generation rates, which are dependent on water availability. Potential releases due to drilling intrusion are also influenced by brine saturations and therefore by *Wicking*. Capillary rise is therefore accounted for. This has been retained as an undisturbed performance characteristic.	▪ **Repository Fluid Flow**
W42	**Fluid Flow Due to Gas Production**	Pressurization of the repository through gas generation could limit the amount of brine that flows into the rooms and drifts. Gas may flow from the repository through the DRZ, impure halite, anhydrite layers, or clay layers. The amount of water available for reactions and microbial activity will impact the amounts and types of gases produced (W44 through W55). Gas generation rates, and therefore repository	▪ **Gas Generation** ▪ **Shafts and Shaft Seals** ▪ **Actinide Transport in the Salado** ▪ **Units Above the Salado**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		pressure, may change as the water content of the repository changes. Pressure changes and *Fluid Flow Due to Gas Production* in the repository and the Salado are accounted for in PA calculations through modeling the two-phase flow. This has been retained as an undisturbed performance characteristic.	
W44	**Degradation of Organic Material**	Microbial breakdown of cellulosic material, and possibly plastics and other synthetic materials, will produce mainly CO_2, but also nitrogen oxide, nitrogen, hydrogen sulfide, hydrogen, and methane. The rate of microbial gas production will depend upon the nature of the microbial populations established, the prevailing conditions, and the substrates present. This has been retained as an undisturbed performance characteristic.	▪ **Gas Generation**
W45	**Effects of Temperature on Microbial Gas Generation**	Gas generation rates used in the PA calculations have been derived from available experimental data. The effects of temperature on microbial gas generation are implicitly incorporated in the gas generation rates used. This has been retained as an undisturbed performance characteristic.	▪ **Gas Generation**
W48	**Effects of Biofilms on Microbial Gas Generation**	The location of microbial activity within the repository is likely to be controlled by the availability of substrates and nutrients. Biofilms may develop on surfaces where nutrients are concentrated. They consist of one or more layers of cells with extracellular polymeric material and serve to maintain an optimum environment for growth. Biofilms can form on almost any moist surface, but their development is likely to be restricted in porous materials. Even so, their development is possible at locations throughout the disposal system. The *Effects of Biofilms on Microbial Gas Generation* may affect disposal system performance through control of microbial population size and their effects on radionuclide transport. The *Effects of Biofilms on Microbial Gas Generation* rates are implicitly incorporated in the gas generation	▪ **Gas Generation**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		rates. Biofilms may also influence contaminant transport rates through their capacity to retain and thus retard both the microbes themselves and radionuclides. This effect is not accounted for in PA calculations, but is considered potentially beneficial to calculated disposal system performance. This has been retained as an undisturbed performance characteristic.	
W49	**Gases from Metal Corrosion**	Oxic corrosion of waste drums and metallic waste will occur at early times following closure of the repository and will deplete its oxygen content. Anoxic corrosion will follow the oxic phase and will produce hydrogen, while consuming water. This has been retained as an undisturbed performance characteristic.	▪ **Gas Generation**
W51	**Chemical Effects of Corrosion**	The predominant *Chemical Effect of Corrosion* reactions on the environment of disposal rooms will be to lower the oxidation state of the brines and maintain reducing conditions. This has been retained as an undisturbed performance characteristic.	▪ **Gas Generation**
W56	**Speciation**	*Speciation* is the estimates of radionuclide solubility in the disposal rooms, and the degree of chemical retardation estimated during contaminant transport. The dependence of actinide retardation on *Speciation* in the Culebra is accounted for in PA calculations by sampling over ranges of distribution coefficients (K_ds). The ranges of K_ds are based on the range of groundwater compositions and *Speciation* in the Culebra, including consideration of nonradionuclide solutes. The concentrations of radionuclides that dissolve in any brines present in the disposal rooms after repository closure will depend on the stability of the chemical species that form under the prevailing conditions (for example, temperature, pressure, and ionic strength). The method used to derive radionuclide solubilities in the disposal rooms considers the expected conditions. This has been retained as an undisturbed performance	▪ **Chemical Conditions** ▪ **Dissolved Actinide Source Term** ▪ **Shafts and Shaft Seals**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		characteristic for the Culebra and disposal rooms only. It was screened out for all other areas.	
W58	**Dissolution of Waste**	The waste that is emplaced within the WIPP contains radionuclides, including actinides or actinide-bearing materials in solid phases, e.g. metal oxides, salts, coprecipitated solids, and contaminated objects. In the event of contact with brine, the solution phase concentration of dissolved radionuclides is controlled both by the solution composition, and by the kinetics of dissolution of the solid phases, effectively approaching equilibrium from undersaturation. Solution complexation reactions of most metal ions with common inorganic ligands, such as carbonated and hydroxide, and with organic ligands such as acetate, citrate, oxalate, and EDTA are kinetically very fast, reaching equilibrium in less than one second, which is infinitesimally small on the time scale of the 10,000 year regulatory period. The rate at which thermodynamic equilibrium is approached between solution composition and the solubility controlling solid phases will be limited by rate of dissolution of the solid materials in the waste. As a result, until equilibrium is reached, the solution concentration of the actinides will be lower than the concentration that is predicted based upon equilibrium of the solution phase components with the solubility limiting solid phases. The assumption of instantaneous equilibrium in waste dissolution reactions is a conservative approach, yielding maximum concentration estimates for radionuclides in the disposal rooms because a time weighted average resulting from a kinetically accurate estimate of solution compositions would have lower concentrations at early times. This has been retained as an undisturbed performance characteristic.	▪ **Dissolved Actinide Source Term**
W61	**Actinide Sorption**	Sorption may be defined as the accumulation of matter at the interface between a solid and	▪ **Colloidal Actinide Source Term**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		an aqueous solution. Sorption of waste contaminants to potentially mobile surfaces, such as colloids, however, may act to enhance chemical transport, particularly if the kinetics of contaminant desorption are slow or the process is irreversible (nonequilibrium). During groundwater flow, any radionuclide sorption processes that occur between dissolved or colloidal actinides and rock surfaces will lead to reduced rates of contaminant transport. The sorptive capacity of the Dewey Lake is sufficiently large to prevent any radionuclides that enter it from being released to the accessible environment over 10,000 years (Wallace et al. 1995). Thus, sorption within the Dewey Lake is accounted for in PA calculations. This has been retained as an undisturbed performance characteristic for the Culebra and Dewey Lake and was screened out for all other areas.	▪ **Shafts and Shaft Seals** ▪ **Actinide Transport in the Salado** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ ***Considered in* Transport of Dissolved Actinides in the Culebra**
W62	**Kinetics of Sorption**	The relevance to the WIPP of sorption reaction kinetics lies in their effects on chemical transport. Sorption of waste contaminants to static surfaces of the disposal system such as seals and host rocks acts to retard chemical transport. Sorption of waste contaminants to potentially mobile surfaces, such as colloids, however, may act to enhance chemical transport, particularly if the kinetics of contaminant desorption are slow or the process is irreversible (nonequilibrium). The potential effects of reaction kinetics in adsorption processes are encompassed in the ranges of distribution coefficients (K_ds) used. This has been retained as an undisturbed performance characteristic for the Culebra and Dewey Lake and was screened out for all other areas.	▪ **Transport of Dissolved Actinides in the Culebra**
W63	**Changes in Sorptive Surfaces**	The geochemical speciation of the Culebra groundwaters and the effects of *Changes in Sorptive Surfaces* are implicitly accounted for	▪ **Transport of Dissolved Actinides in the Culebra**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		in PA calculations for the WIPP in the ranges of K_ds used. This has been retained as an undisturbed performance characteristic.	
W64	**Effects of Metal Corrosion**	Ferrous metals will be the most abundant metals in the WIPP, and these will corrode on contact with any brines entering the repository. Initially, corrosion will occur under oxic conditions owing to the atmospheric oxygen present in the repository at the time of closure. However, consumption of the available oxygen by corrosion reactions will rapidly lead to anoxic (reducing) conditions. These changes and controls on conditions within the repository will affect the chemical *Speciation* of the brines and may affect the oxidation states of the actinides present. Changes to the oxidation states of the actinides will lead to changes in the concentrations that may be mobilized during brine flow. The oxidation states of the actinides are accounted for in PA calculations by the use of parameters that describe probabilities that the actinides exist in particular oxidation states and, as a result, the likely actinide concentrations. Therefore, the *Effect of Metal Corrosion* is accounted for in PA calculations. This has been retained as an undisturbed performance characteristic.	▪ **Chemical Conditions**
W66	**Reduction-Oxidation Kinetics**	The lack of data characterizing the rates of reactions among trace element reduction-oxidation couples leads to uncertainty in elemental speciation. This uncertainty in *Reduction-Oxidation Kinetics* is accounted for in PA calculations in the dissolved actinide source term model, which estimates the probabilities that particular actinides occur in certain oxidation states. This has been retained as an undisturbed performance characteristic.	▪ **Chemical Conditions** ▪ **Dissolved Actinide Source Term**
W68	**Organic Complexation**	Some *Organic Ligands* can increase the actinide solubilities. An estimate of the complexing agents in the transuranic solidified waste forms scheduled for disposal in WIPP is used. Acetate, citrate, oxalate, and EDTA were determined to be the only water-	▪ ***Influences* Chemical Conditions**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		soluble and actinide complexing organic ligands present in significant quantities. These ligands and their complexation with actinides (Th(IV), U(VI), Np(V), and Am(III)) in a variety of ionic strength media were studied. The studies showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved actinide concentrations. Lactate behavior was also studied because it appeared in the preliminary inventory of nonradioactive constituents of the TRU waste to be emplaced in the WIPP. This has been retained as an undisturbed performance characteristic.	
W69	**Organic Ligands**	Some *Organic Ligands* can increase the actinide solubilities. An estimate of the complexing agents in the transuranic solidified waste forms scheduled for disposal in WIPP is used. Acetate, citrate, oxalate, and EDTA were determined to be the only water-soluble and actinide complexing organic ligands present in significant quantities. These ligands and their complexation with actinides (Th(IV), U(VI), Np(V), and Am(III)) in a variety of ionic strength media were studied. The studies showed that acetate, citrate, oxalate, and EDTA are capable of significantly enhancing dissolved actinide concentrations. Lactate behavior was also studied because it appeared in the preliminary inventory of nonradioactive constituents of the TRU waste to be emplaced in the WIPP. This has been retained as an undisturbed performance characteristic.	▪ ***Influences*** **Chemical Conditions**
W70	**Humic and Fulvic Acids**	The occurrence of *Humic and Fulvic Acids* is incorporated in PA calculations in the models for radionuclide transport by humic colloids. This has been retained as an undisturbed performance characteristic.	▪ **Colloidal Actinide Source Term**
W74	**Chemical Degradation of Seals**	The concrete used in the seal systems will degrade due to chemical reaction with the infiltrating groundwater. Degradation could lead to an increase in permeability of the seal	▪ **Shafts and Shaft Seals**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		system. The main uncertainties with regard to cement degradation rates at the WIPP are the effects of groundwater chemistry, the exact nature of the cementitious phases present, and the rates of brine infiltration. The PA calculations take a conservative approach to these uncertainties by assuming a large increase in permeability of the concrete seals only a few hundred years after closure. These permeability values are based on seal design considerations and consider the potential effects of degradation processes. This has been retained as an undisturbed performance characteristic.	
W76	**Microbial Growth on Concrete**	Concrete can be inhabited by alkalophilic bacteria, which could produce acids, thereby accelerating the seal degradation process. Nitrification processes, which will produce nitric acid, tend to be aerobic, and will be further limited at the WIPP by the low availability of ammonium in the brines. Because of the limitations on growth because of the chemical conditions, it is likely that the effects of *Microbial Growth on Concrete* will be small. The effects of such microbial activity on seal properties are, therefore, implicitly accounted for in PA calculations through the CDFs used for seal material permeabilities. This has been retained as an undisturbed performance characteristic.	▪ **Shafts and Shaft Seals**
W77	**Solute Transport**	*Solute Transport* may occur by advection, dispersion, and diffusion down chemical potential gradients, and is accounted for. This has been retained as an undisturbed performance characteristic.	▪ **Units Above Salado** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ ***Considered in* Transport of Dissolved Actinides in the Culebra**
W78	**Colloid Transport**	*Colloid Transport* may occur at different rates than those of fully dissolved species. They may be physically excluded from fine porous media, and their migration may be accelerated through fractured media in channels where velocities are greatest. This has been retained	▪ **Actinide Transport in the Salado** ▪ **Transport of Colloidal Actinides in the Culebra**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		as an undisturbed performance characteristic.	
W79	**Colloid Formation and Stability**	*Colloid Formation and Stability* depends on their composition and the prevailing chemical conditions (for example, salinity) and is accounted for in PA calculations through estimates of colloid numbers in the disposal room based on the prevailing chemical conditions. This has been retained as an undisturbed performance characteristic.	▪ **Colloidal Actinide Source Term**
W80	**Colloid Filtration**	Colloids can also interact with the host rocks during transport and become retarded. These interactions may be of a chemical or physical nature and include electrostatic effects, leading to *Colloid Sorption*, and sieving leading to *Colloid Filtration* and pore blocking. This has been retained as an undisturbed performance characteristic.	▪ **Actinide Transport in the Salado**
W81	**Colloid Sorption**	Colloids can also interact with the host rocks during transport and become retarded. These interactions may be of a chemical or physical nature and include electrostatic effects, leading to *Colloid Sorption*, and sieving leading to *Colloid Filtration* and pore blocking. This has been retained as an undisturbed performance characteristic.	▪ **Actinide Transport in the Salado** ▪ **Transport of Colloidal Actinides in the Culebra**
W82	**Suspension of Particles**	*Suspensions of Particles* larger than colloids are generally unstable and do not persist for very long. The only reasonable conditions under which suspensions could be formed would be during a drilling event with particles of waste suspended in the drilling fluid are carried to the surface. This has been retained as a disturbed performance characteristic.	▪ **Cuttings and Cavings** ▪ **Spalling**
W84	**Cuttings**	Inadvertent human intrusion into the repository by a borehole could result in transport of waste material to the ground surface through drilling-induced flow and blowouts (FEPs H21 and H23). This waste could include material intersected by the drill bit (*Cuttings*), material eroded from the borehole wall by circulating drilling fluid (*Cavings*), and material that enters the borehole as the repository depressurizes	▪ **Cuttings and Cavings** ▪ **Spalling**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		(*Spallings*). Transport of radionuclides by these materials and in brine is accounted for in PA calculations. This has been retained as a disturbed performance characteristic.	
W85	**Cavings**	Inadvertent human intrusion into the repository by a borehole could result in transport of waste material to the ground surface through drilling-induced flow and blowouts (FEPs H21 and H23). This waste could include material intersected by the drill bit (*Cuttings*), material eroded from the borehole wall by circulating drilling fluid (*Cavings*), and material that enters the borehole as the repository depressurizes (*Spallings*). Transport of radionuclides by these materials and in brine is accounted for in PA calculations. This has been retained as a disturbed performance characteristic.	▪ **Cuttings and Cavings** ▪ **Spalling**
W86	**Spallings**	Inadvertent human intrusion into the repository by a borehole could result in transport of waste material to the ground surface through drilling-induced flow and blowouts (FEPs H21 and H23). This waste could include material intersected by the drill bit (*Cuttings*), material eroded from the borehole wall by circulating drilling fluid (*Cavings*), and material that enters the borehole as the repository depressurizes (*Spallings*). Transport of radionuclides by these materials and in brine is accounted for in PA calculations. This has been retained as a disturbed performance characteristic.	▪ **Cuttings and Cavings** ▪ **Spalling**
W87	**Microbial Transport**	Microbes will be introduced into the disposal rooms during the operational phase of the repository and will also occur naturally in geological units throughout the disposal system. Because of their colloidal size, microbes, and any radionuclides bound to them, may be transported at different rates than radionuclides in solution. This has been retained as an undisturbed performance characteristic.	▪ **Transport of Colloidal Actinides in the Culebra**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
W90	**Advection**	The transport of dissolved and solid material by flowing fluid is accounted for in PA calculations. This has been retained as an undisturbed performance characteristic.	▪ **Culebra Geometry** ▪ **Actinide Transport in the Salado** ▪ **Units Above the Salado** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ **Transport of Colloidal Actinides in the Culebra**
W91	**Diffusion**	The movements of molecules or particles both parallel to and transverse to the direction of advection in response to Brownian forces are accounted for in PA calculations. This has been retained as an undisturbed performance characteristic.	▪ **Actinide Transport in the Salado** ▪ **Units Above the Salado** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ **Transport of Colloidal Actinides in the Culebra**
W92	**Matrix Diffusion**	Movement is transverse to the direction of advection within a fracture and into the surrounding rock matrix, is accounted for in PA calculations. This has been retained as an undisturbed performance characteristic.	▪ **Actinide Transport in the Salado** ▪ **Transport of Dissolved Actinides in the Culebra**
H1	**Oil and Gas Exploration**	Drilling associated with *Oil and Gas Exploration* and *Oil and Gas Exploitation* currently takes place in the vicinity of the WIPP. For example, gas is extracted from reservoirs in the Morrow Formation, some 4,200 m (14,000 ft) below the surface, and oil is extracted from shallower units within the Delaware Mountain Group, some 2,150 to 2,450 m (7,000 to 8,000 ft) below the surface. Thus, consistent with 40 CFR § 194.33(b)(3)(i), the DOE has used the historical record of deep drilling associated with *Oil and Gas Exploration, Potash*	▪ **Cuttings and Cavings** ▪ **Spalling**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		Exploration, Oil and Gas Exploitation, Enhanced Oil and Gas Recovery, and *Drilling Associated With Other* resources (sulfur exploration) in the Delaware Basin in calculations to determine the rate of future deep drilling in the Delaware Basin This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	
H2	**Potash Exploration**	Potash resources in the vicinity of the WIPP are discussed in Section 2.3.1.1. Throughout the Carlsbad Potash District, commercial quantities of potash are restricted to the McNutt, which forms part of the Salado above the repository horizon. *Potash Exploration* and evaluation boreholes have been drilled within and outside the controlled area. Such drilling will continue outside the WIPP land withdrawal boundary, but no longer occurs within the boundary due to transfer of rights and controls to the DOE. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Cuttings and Cavings** ▪ **Spalling**
H4	**Oil and Gas Exploitation**	Drilling associated with *Oil and Gas Exploration* and *Oil and Gas Exploitation* currently takes place in the vicinity of the WIPP. For example, gas is extracted from reservoirs in the Morrow Formation, some 4,200 m (14,000 ft) below the surface, and oil is extracted from shallower units within the Delaware Mountain Group, some 2,150 to 2,450 m (7,000 to 8,000 ft) below the surface. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Cuttings and Cavings** ▪ **Spalling**
H8	**Other Resources**	*Drilling for Other Resources* has taken place within the Delaware Basin. For example,	▪ **Cuttings and Cavings**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		sulfur extraction using the Frasch process began in 1969 and continued for three decades at the Culberson County Rustler Springs mine near Orla, Texas. In addition, brine wells have been in operation in and about the Delaware Basin for at least as long. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Spalling**
H9	**Enhanced Oil and Gas Recovery**	Drilling for the purposes of reservoir stimulation and subsequent *Enhanced Oil and Gas Recovery* does take place within the Delaware Basin, although systematic, planned waterflooding has not taken place near the WIPP. Instead, injection near WIPP consists of single-point injectors, rather than broad, grid-type waterflood projects (Hall et al. 2003). In the vicinity of the WIPP, fluid injection usually takes place using boreholes initially drilled as producing wells. Therefore, regardless of the initial intent of a deep borehole, whether in search of petroleum reserves or as an injection point, the drilling event and associated processes are virtually the same. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Cuttings and Cavings** ▪ **Spalling**
H13	**Conventional Underground Potash Mining**	Potash is the only known economically viable resource in the vicinity of the WIPP that is recovered by underground mining. Potash is mined by conventional techniques extensively in the region east of Carlsbad and up to 2.4 km (1.5 mi) from the boundaries of the controlled area of the WIPP. According to existing plans and leases, potash mining is expected to continue in the vicinity of the WIPP in the near future. The DOE assumes that all economically recoverable potash in the vicinity of the disposal system will be extracted in the near future, although there are no economical reserves above the WIPP waste panels. *Conventional Underground Potash Mining* is currently taking place and is	▪ ***Considered in the following:* Transport of Dissolved Actinides in the Culebra** ▪ **Transport of Colloidal Actinides in the Culebra**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		expected to continue in the vicinity of the WIPP in the near future. The potential effects of HCN, and future *Conventional Underground Potash Mining* are accounted for in PA calculations as prescribed by 40 CFR § 194.32 (b). This has been retained as a disturbed performance characteristic for future events and undisturbed performance characteristic for historical, current, and near future events.	
H21	**Drilling Fluid Flow**	For the future, drill holes may intersect the waste disposal region and their effects could be more profound. Thus, the possibility of a future borehole penetrating a waste panel, so that *Drilling Fluid Flow* and, potentially, *Blowout*, results in transport of radionuclides to the land surface or to overlying hydraulically conductive units. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Cuttings and Cavings** ▪ **Spalling**
H22	**Drilling Fluid Loss**	In evaluating the potential consequences of Drilling Fluid Loss to a waste panel, two types of drilling events need to be considered.; those that intercept pressurized fluid in underlying formations such as the Castile (E1 events), and those that do not (E2 events). A possible hydrological effect would be to make a greater volume of brine available for gas generation processes and thereby increase gas volumes at particular times in the future. Of boreholes that intersect a waste panel in the future, 8 percent are assumed to be E1 events and 92 percent are E2 events. For either type of drilling event, on the basis of current drilling practices, the driller is assumed to pass through the repository rapidly. Relatively small amounts of drilling fluid loss may not be noticed and may not give rise to concern. Larger fluid losses would lead to the driller injecting materials to reduce permeability, or to the borehole being cased and cemented, to limit the loss of drilling fluid.	▪ ***Considered in the following:* Multiple Intrusions** ▪ **Exploration Boreholes** ▪ **Direct Brine Release**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		For boreholes that intersect pressurized brine reservoirs, the volume of fluid available to flow up a borehole will be significantly greater than the volume of any drilling fluid that could be lost. This greater volume of brine is accounted for in PA calculations, and is allowed to enter the disposal room. Thus, the effects of Drilling Fluid Loss will be small by comparison to the potential flow of brine from pressurized brine reservoirs. Therefore, the effects of drilling fluid loss for E1 drilling events have been eliminated from PA calculations on the basis of low consequence to the performance of the disposal system. For boreholes that do not intersect pressurized brine reservoirs the treatment of the disposal room implicitly accounts for the potential for greater gas generation resulting from Drilling Fluid Loss. Thus, the hydrological effects of drilling fluid loss for E2 drilling events are accounted for in PA calculations. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	
H23	**Blowouts**	*Blowouts* are short-term events that can result in the flow of pressurized fluid from one geologic stratum to another. Fluid could flow from pressurized zones through the borehole to the land surface (*Blowout*) or to a thief zone. Such drilling-related events could influence groundwater flow and, potentially, radionuclide transport in the affected units. Movement of brine from a pressurized zone, through a borehole, into potential thief zones such as the Salado interbeds or the Culebra, could result in geochemical changes and altered radionuclide migration rates in these units. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Direct Brine Release**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
H24	**Drilling-Induced Geochemical Changes**	Radionuclide migration rates are governed by the coupled effects of hydrological and geochemical processes. Human Events and Processes outside the controlled area could affect the geochemistry of units within the controlled area if they occur sufficiently close to the edge of the controlled area. Movement of brine from a pressurized reservoir in the Castile through a borehole into potential thief zones, such as the Salado interbeds or the Culebra, could cause *Drilling-Induced Geochemical Changes* resulting in altered radionuclide migration rates in these units through their effects on colloid transport and sorption (colloid transport may enhance radionuclide migration, while radionuclide migration may be retarded by sorption). This has been retained as a disturbed performance characteristic for future events and undisturbed performance characteristic for historical, current, and near future events.	▪ ***Considered in the following:*** ▪ **Multiple Intrusions** ▪ **Exploration Boreholes** ▪ **Direct Brine Release** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ **Transport of Colloidal Actinides in the Culebra**
H30	**Fluid-Injection Induced Geochemical Changes**	Injection of fluids through a leaking borehole could affect the geochemical conditions in thief zones, such as the Salado interbeds or the Culebra. Such *Fluid Injection-Induced Geochemical Changes* could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area through their effects on colloid transport and sorption. This has been screened out for future events and retained as an undisturbed performance characteristic for historical, current, and near future events.	▪ ***Considered in the following:*** ▪ **Multiple Intrusions** ▪ **Exploration Boreholes** ▪ **Direct Brine Release** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ **Transport of Colloidal Actinides in the Culebra**
H31	**Natural Borehole Fluid Flow**	A future borehole that penetrates a Castile brine reservoir could provide a connection for brine flow from the reservoir to the waste panel, thus increasing fluid pressure and brine volume in the waste panel. Long-term *Natural Borehole Flow* through such a borehole is accounted for in PA calculations. Deep abandoned boreholes that intersect the Salado	▪ **Units Above the Salado** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ **Multiple Intrusions**

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		interbeds near the waste disposal panels could provide pathways for long-term radionuclide transport from the waste panels to the land surface or to overlying units. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **Exploration Boreholes**
H32	**Waste-Induced Borehole Flow**	An abandoned future borehole that intersects a waste panel could provide a connection for contaminant transport away from the repository horizon. If the borehole has degraded casing and/or plugs, and the fluid pressure within the waste panel is sufficient, radionuclides could be transported to the land surface. Additionally, if brine flows through the borehole to overlying units, such as the Culebra, it may carry dissolved and colloidal actinides that can be transported laterally to the accessible environment by natural groundwater flow in the overlying units. This has been retained as a disturbed performance characteristic for future events and screened out for historical, current, and near future events.	▪ **BRAGFLO** ▪ **Units Above the Salado** ▪ **Multiple Intrusions** ▪ **Exploration Boreholes**
H36	**Borehole-Induced Geochemical Changes**	Movement of fluids through abandoned boreholes could result in *Borehole*-Induced Geochemical Changes in the receiving units such as the Salado interbeds or Culebra. Such geochemical changes could alter radionuclide migration rates within the disposal system in the affected units if they occur sufficiently close to the edge of the controlled area, or if they occur as a result of flow through existing boreholes within the controlled area through their effects on colloid transport and sorption. This has been retained as a disturbed performance characteristic for future events and undisturbed performance characteristic for historical, current, and near future events.	▪ ***Considered in the following:*** ▪ **Multiple Intrusions** ▪ **Exploration Boreholes** ▪ **Direct Brine Release** ▪ **Transport of Dissolved Actinides in the Culebra** ▪ **Transport of Colloidal Actinides in the Culebra**
H37	**Changes in Groundwater Flow Due to Mining**	Excavation activities may result in hydrological disturbances of the disposal system. Subsidence associated with	▪ **Units Above the Salado** ▪ ***Considered in***

TABLE FOR RETAINED FEATURES, EVENTS, AND PROCESSES FOR THE PERFORMANCE ASSESSMENT MODELS

FEP ID#	FEP NAME	DESCRIPTION	MODEL APPLICATION
		excavations may affect groundwater flow patterns through increased hydraulic conductivity within and between units. Fluid flow associated with excavation activities may also result in changes in brine density and geochemistry in the disposal system. This has been retained as a disturbed performance characteristic for future events and undisturbed performance characteristic for historical, current, and near future events. NOTE: H38 says that the H37 HCN was screened out, but the text for H37 says it was left in.	**Transport of Dissolved Actinides in the Culebra**
H41	**Surface Disruptions**	The only surface activity that has the potential to affect the disposal system is potash tailings, salt tailings (both potash and WIPP) and effluent disposal. Potash tailings ponds may act as sources of focused recharge to the Dewey Lake and Rustler units. This has been screened out for future events and retained as an undisturbed performance characteristic for historical, current, and near future events.	▪ ***Influences*** ▪ **Units Above the Salado**
H57	**Loss of Records**	DOE no longer takes credit for passive institutional controls in PA, effectively assuming that all public records and archives relating to the repository are lost 100 years after closure. Therefore, DOE continues to include the *Loss of Records* FEP within PA and does not include credit for passive institutional controls. This has been retained as a disturbed performance characteristic for future events.	▪

Attachment 2

Model Summary

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Disposal System Geometry	**Salado Flow and Transport**	Sets the modeled physical dimension and establishes the flow path of the Salado formation, which are used are used by other models.	**N1 Stratigraphy N23 Saturated Groundwater Flow N24 Unsaturated Groundwater Flow N39 Physiography**	▪ **BRAGFLO** ▪ **(Brine And Gas Flow)**
Culebra Hydrology	**Non-Salado Flow and Transport**	This model conceptualizes the Culebra region as a confined aquifer with a heterogeneous porous medium that has variations in transmissivity. This model is used because the other regions above the Salado are considered impermeable and the Culebra is the only region that could allow transport of radionuclides to the accessible environment.	**N1 Stratigraphy N53 Groundwater discharge N54 Groundwater recharge W90 Advection**	▪ **MODFLOW-2000** ▪ **PEST** ▪ **SECOTP2D**
Repository Fluid Flow	**Salado Flow and Transport**	This model is concerned with fluid flow and distribution in the waste; fluid flow to and from the Salado and shafts; and, fluid flow between the repository and boreholes.	**W1 Disposal geometry H32 Waste-induce borehole**	▪ **BRAGFLO**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Salado	**Salado Flow and Transport**	The purpose of this model is to reasonably represent the effects of fluid flow in the Salado on long-term performance of the disposal system. Fluid flow is considered because liquid could move from the Salado to the repository because of gradients and could interact with creep closure, gas generation, actinide solubilities, and other repository processes AND gas generated in the repository may be capable of fracturing the Salado interbeds, creating increased permeability channels that may be pathways for lateral transport. The two rock types used to represent the intact Salado are impure halite and anhydrite.	**No FEPs identified or this model. It supplies input parameters for Salado Interbeds, Repository Fluid Flow, and Actinide Transport in the Salado**	▪ **BRAGFLO**
Impure Halite	**Salado Flow and Transport**	This model uses a single porous medium with spatially constant rock and hydrologic properties to represent intact, halite rich layers in the Salado and minor interbeds contained within those layers that are not specifically modeled.	**N1 Stratigraphy** **DRZ supports this model.**	▪ **BRAGFLO**
Salado Interbeds	**Salado Flow and Transport**	The interbeds were chosen because they exist in the disturbed region around the repository and can serve as conduits for brine flow between the impure halite and the repository.	**W25 Disruption caused by gas effects.** **W23 Saturated groundwater flow.** **DRZ supports this model.**	▪ **BRAGFLO** ▪ **Latin Hypercube Sampling**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Disturbed Rock Zone (DRZ)	**Salado Flow and Transport**	The increase in the DRZ permeability increases the ability of fluid to flow from interbeds to the waste disposal region.	**W18 Disturbed rock zone. W22 Roof falls. W27 Gas explosion N12 Seismic activity W39 Underground boreholes**	▪ **BRAGFLO**
Actinide Transport in the Salado	**Salado Flow and Transport**	This model represents the transport of actinides in the Salado and is conceptualized by the transport only occurring through advection as described in the Salado Model.	**W90 Advection W91 Diffusion W92 Matrix diffusion W42 Fluid flow caused by gas production W61 Actinide sorption W78 Colloid transport W80 Colloid filtration W81 Colloid sorption N25 Fracture flow W12 Radioactive decay and ingrowth**	▪ **NUTS** ▪ **NUTS receives input parameters from BRAGFLO; velocity field, pressures, porosities, saturations, geometrical grid, residual saturation, material map, brine compressibility, and time step.**
Units Above the Salado	**Non-Salado Flow and Transport**	This model represents a reasonable and realistic basis for simulations of fluid flow within the disposal systems and simulations of groundwater flow	**N16 Shallow dissolution N23 Saturated groundwater flow N24 Unsaturated**	▪ **MODFLOW-2000** ▪ **PEST** ▪ **SECOTP2D** ▪ **Monte Carlo simulation**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Units Above the Salado (cont.)	**Non-Salado Flow and Transport**	and radionuclide transport in the Culebra. The units above the Salado are the Los Medaños, the Culebra, the Tamarisk. the Magenta, the Forty-niner, the Dewey Lake, and the units above Dewey Lake. Culebra is the only region that could allow transport of radionuclides to the accessible environment.	**groundwater flow** **N25 Fracture Flow** **N27 Effects of preferential pathways** **N53 Groundwater discharge** **N54 Groundwater recharge** **N55 Infiltration** **N56 Changes in groundwater recharge and discharge** **N59 Precipitation** **N60 Temperature** **N61 Climate Change** **W42 Fluid flow caused by gas production** **W77 Solute transport** **W90 Advection** **W91 Diffusion** **H31 Natural borehole fluid flow** **H32 Waste-Induced borehole flow** **H37 Changes in**	

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
			groundwater flow caused by mining	
Transport of Dissolved Actinides in the Culebra	**Non-Salado Flow and Transport**	This model represents actinides being introduced to the Culebra by brine flowing into the region up a borehole or shaft. Primary factors in this model are: velocities of fluid in the advective porosity, free-water diffusion coefficients, and dispersion coefficients.	**W61 Actinide sorption** **W62 Kinetics of sorption** **W63 Changes in sorptive surfaces** **W77 Solute transport** **W90 Advection** **W91 Diffusion** **W92 Matrix diffusion** **N36,37 Groundwater geochemistry** **H31 Natural borehole fluid flow**	▪ **SECOTP2D** ▪ **Receives input from MODFLOW-2000**
Transport of Colloidal Actinides in the Culebra	**Non-Salado Flow and Transport**	This model is very similar to the dissolved model. There is a potential that colloidal particles will transport faster than the dissolved actinides, they can be filtered by small-aperture features, and the sorption process may be different.	**W78 Colloidal transport** **W81 Colloidal sorption** **W87 Microbial transport** **W90 Advection** **W91 Diffusion**	▪ **SECOTP2D**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Exploration Boreholes	**Human Intrusion**	This model uses historical information to develop a frequency for drilling.	**No specific FEPs. The purpose is to develop a drilling frequency to be used in other models that considers Human Intrusion.**	▪ **Simple math from historical information**
Cuttings and Cavings	**Human Intrusion**	This model estimates the quantity of actinides released as solids directly to the surface. by drilling through the waste (cuttings) and the drilling fluid eroding the walls of the borehole (cavings). The cuttings model principle parameter is the diameter of the drill bit (i.e. larger diameter, the more waste). The cavings model considers the drilling mud properties, drilling rates, drill string angular velocity, and the shear resistance of the waste.	**H1 Oil and gas exploration H2 Potash exploration H4 Oil and gas exploitation H8 Other resources H9 Enhanced oil and gas recovery H21 Drilling fluid flow W82 Suspension of particles W84 Cuttings W85 Cavings**	▪ **CUTTINGS_S** ▪ **CCDFGF**
Spallings	**Human Intrusion**	This model estimates the quantity of actinides released as solids to the surface due to the field pressure difference between the repository and the bottom of the borehole and	**H1 Oil and gas exploration H2 Potash exploration H4 Oil and gas exploitation**	▪ **DRSPALL** ▪ **CCDFGF**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Spallings (cont.)	**Human Intrusion**	entrainment in the drill mud. The primary parameters are gas pressure in the repository when it is penetrated and waste properties for permeability, tensile strength, and particle diameter.	**H8 Other resources** **H9 Enhanced oil and gas recovery** **H21 Drilling fluid flow** **W82 Suspension of particles** **W84 Cuttings** **W85 Cavings** **W86 Spalling**	
Direct Brine Release	**Human Intrusion**	This model estimates the quantity of brine released to the surface if a driller penetrates the repository and brings contaminated brine to the surface. This type of release was not accounted for in the cutting, caving, and spalling models.	**H23 Blowouts**	▪ **BRAGFLO** ▪ **PANEL** ▪ **CCDFGF**
Castile Brine Reservoir	**Human Intrusion**	This model includes the possibility that a brine reservoir is under the repository and assumes a probability of a borehole intersecting the brine and the resulting actions.	**N2 Brine reservoir Blowouts**	▪ **BRAGFLO**
Multiple Intrusions	**Human Intrusion**	This model takes the drilling frequency and performs a probability analysis of multiple intrusions into the repository.	**See Exploration Boreholes**	▪

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Climate Change	**Non-Salado Flow and Transport**	This model considers only the possible climate changes which could affect the groundwater flow and potential radionuclide transport. It uses precipitation, temperature, and evapotranspiration as related to recharge for the 10,000 year period.	**N59 Precipitation** **N60 Temperature** **N61 Climate change**	▪ **SECOTP2D** ▪ **Receives input from MODFLOW-2000**
Creep Closure	**Salado Flow and Transport**	Creep closure will occur and change porosity and permeability in the disposal area. Brine, gas, and air inside of the area can slow consolidation and closure and are taken into account for this model.	**W19 Excavation-induced changes in stress** **W20 Salt creep** **W21 Changes in the stress field** **W26 Pressurization** **W32 Consolidation of waste**	▪ **BRAGFLO** ▪ **SANTOS**
Shafts and Shaft Seals	**Salado Flow and Transport**	This model represents the closure of the four shafts. The materials used for closure and sealing along with the surrounding DRZ healing are considered for permeability.	**W1 Disposal Geometry** **W6 Seal Geometry** **W7 Seal Physical Properties** **W18 DRZ** **W20 Salt Creep** **W36 Consolidation of Seals** **W37 Mechanical**	▪ **BRAGFLO** ▪ **NUTS** ▪ **SPECTROM-32** ▪ **SWIFT II** ▪ **TOUGH2**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Shafts and Shaft Seals (cont.)	**Salado Flow and Transport**		**Degradation of Seals W74 Chemical Degradation of Seals W76 Microbial Growth on Concrete W56 Speciation W61 Actinide Sorption**	
Gas Generation	**Salado Flow and Transport**	Gas will be generated from multiple sources and must be estimated. The other models which rely on this is; the Disposal System, Creep Closure, Salado Interbeds, and Spallings.	**W2 Waste inventory W5 Container material inventory W40 Brine inflow W44 Consumption of cellulosics, plastics, and rubber (CPR) W45 Effects of temperature on microbial gas generation W48 Effects of biofilms on microbial gas generation W49 Gases from metal corrosion W51 Chemical effects of corrosion**	▪ **BRAGFLO**

Model Summary

Conceptual Model	Component Modeled	General Comment	Associated FEPs	Computational Model
Chemical Conditions	**Salado Flow and Transport**	This model represents the conditions in the repository to determine actinide solubility. MgO is also considered because it should reduce the actinide solubilities.	**W3 Heterogeneity of waste** **W10 Backfill chemical composition** **W56 Speciation** **W64 Effects of metal corrosion** **W66 Redox kinetics**	▪ **NUTS** ▪ **PANEL**
Dissolved Actinide Source Term	**Salado Flow and Transport**	This model represents the aqueous concentrations of thorium, uranium, plutonium, and americium in the repository. It considers the reducing nature of the environment and estimates the solubility's for various oxidation states	**W2 Waste Inventory** **W3 Heterogeneity of waste** **W56 Speciation** **W58 Dissolution of waste** **W66 Redox kinetics**	▪ **NUTS** ▪ **PANEL**
Colloidal Actinide Source Term	**Salado Flow and Transport**	This model uses four types of colloidal particles to cover the range of possible behavior for all colloidal types. The concentration of each actinide element on each colloidal particle type has been fixed and the model uses the "inventory-limited" concept.	**W61 Actinide sorption** **W70 Humic and fulvic acids** **W79 Colloid formation and stability**	▪ **NUTS** ▪ **PANEL**

Attachment 3

FEP Category Table

FEP Category Table

FEP Category Table

FEP Type	FEP ID#	FEP NAME
Agency	W06	Seal Geometry
Agency	W07	Seal Physical Properties
Agency	W18	Disturbed Rock Zone (DRZ)
Agency	W36	Consolidation of Seals
Agency	W37	Mechanical Degradation of Seals
Regulatory	H01	Oil and Gas Exploration
Regulatory	H02	Potash Exploration
Regulatory	H04	Oil and Gas Exploitation
Regulatory	H08	Other Resources
Regulatory	H09	Enhanced Oil and Gas Recovery
Regulatory	H13	Conventional Underground Potash Mining
Regulatory	H21	Drilling Fluid Flow
Regulatory	H22	Drilling Fluid Loss
Regulatory	H23	Blowouts
Regulatory	H24	Drilling-Induced Geochemical Changes
Regulatory	H30	Fluid-Injection Induced Geochemical Changes
Regulatory	H31	Natural Borehole Fluid Flow
Regulatory	H32	Waste-Induced Borehole Flow
Regulatory	H36	Borehole-Induced Geochemical Changes
Regulatory	H37	Changes in Groundwater Flow Due to Mining
Regulatory	H41	Surface Disruptions
Regulatory	H57	Loss of Records
Regulatory	W39	Underground Boreholes

FEP Category Table

FEP Type	FEP ID#	FEP NAME
Regulatory	W82	Suspension of Particles
Regulatory	W84	Cuttings
Regulatory	W85	Cavings
Regulatory	W86	Spallings
Scientific	N01	Stratigraphy
Scientific	N02	Brine Reservoir
Scientific	N08	Formation of Fractures
Scientific	N09	Changes in Fracture Properties
Scientific	N12	Seismic Activity
Scientific	N16	Shallow Dissolution, including Lateral Dissolution
Scientific	N23	Saturated Groundwater Flow
Scientific	N24	Unsaturated Groundwater Flow
Scientific	N25	Fracture Flow
Scientific	N27	Effects of Preferential Pathways
Scientific	N33	Groundwater Geochemistry
Scientific	N39	Physiography
Scientific	N53	Groundwater Discharge
Scientific	N54	Groundwater Recharge
Scientific	N55	Infiltration
Scientific	N56	Changes in Groundwater Recharge and Discharge
Scientific	N59	Precipitation
Scientific	N60	Temperature
Scientific	N61	Climate Change
Scientific	N71	Microbes
Scientific	W01	Disposal Geometry

FEP Category Table

FEP Type	FEP ID#	FEP NAME
Scientific	W02	**Waste Inventory**
Scientific	W03	**Heterogeneity of Waste Forms**
Scientific	W05	**Container Material Inventory**
Scientific	W10	**Backfill Chemical Composition**
Scientific	W12	**Radionuclide Decay and In-Growth**
Scientific	W19	**Excavation Induced Changes in Stress**
Scientific	W20	**Salt Creep**
Scientific	W21	**Changes in the Stress Field**
Scientific	W22	**Roof Falls**
Scientific	W25	**Disruption Due to Gas Effects**
Scientific	W26	**Pressurization**
Scientific	W27	**Gas Explosions**
Scientific	W32	**Consolidation of Waste**
Scientific	W40	**Brine Inflow**
Scientific	W41	**Wicking**
Scientific	W42	**Fluid Flow Due to Gas Production**
Scientific	W44	**Degradation of Organic Material**
Scientific	W45	**Effects of Temperature on Microbial Gas Generation**
Scientific	W48	**Effects of Biofilms on Microbial Gas Generation**
Scientific	W49	**Gases from Metal Corrosion**
Scientific	W51	**Chemical Effects of Corrosion**
Scientific	W56	**Speciation**
Scientific	W58	**Dissolution of Waste**
Scientific	W61	**Actinide Sorption**
Scientific	W62	**Kinetics of Sorption**
Scientific	W63	**Changes in Sorptive Surfaces**

FEP Category Table

FEP Type	FEP ID#	FEP NAME
Scientific	W64	**Effects of Metal Corrosion**
Scientific	W66	**Reduction-Oxidation Kinetics**
Scientific	W68	**Organic Complexation**
Scientific	W69	**Organic Ligands**
Scientific	W70	**Humic and Fulvic Acids**
Scientific	W74	**Chemical Degradation of Seals**
Scientific	W76	**Microbial Growth on Concrete**
Scientific	W77	**Solute Transport**
Scientific	W78	**Colloid Transport**
Scientific	W79	**Colloid Formation and Stability**
Scientific	W80	**Colloid Filtration**
Scientific	W81	**Colloid Sorption**
Scientific	W87	**Microbial Transport**
Scientific	W90	**Advection**
Scientific	W91	**Diffusion**
Scientific	W92	**Matrix Diffusion**