Appendix PA

Attachment MASS

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ACRONYMS ***AND ABBREVIATIONS***

An	***actinide***
ASTP	***Actinide Source Term Program***
BSEP	Brine Sampling and Evaluation Program
CCDF	complementary cumulative distribution function
CH	contact-handled
CCA	***Compliance Certification Application***
CPR	***cellulosic, plastic, and rubber***
CRA	***Compliance Recertification Application***
~~CSH~~	~~calcium-silicate-hydrate~~
DCCA	Draft Compliance Certification Application
DOE	U.S. Department of Energy
DRZ	disturbed rock zone
DSEIS	Draft Supplement, Environmental Impact Statement
~~EEG~~	~~Environmental Evaluation Group~~
~~EIS~~	~~Environmental Impact Statement~~
EPA	U.S. Environmental Protection Agency
~~ERDA~~	~~U.S. Energy Research and Development Administration~~
FEIS	Final Environmental Impact Statement
FEP***s***	features, events, and processes
FMT	***Fracture-Matrix Transport***
FSEIS	Final Supplemental Environmental Impact Statement
LANL	Los Alamos National Laboratory
LEFM	linear elastic fracture mechanics
LLNL	Lawrence Livermore National Laboratory
MB	marker bed
~~NAS~~	~~National Academy of Sciences~~
~~NIST~~	~~National Institute of Standards and Technology~~
~~ORNL~~	~~Oak Ridge National Laboratory~~
PA	***performance assessment***
PAVT	***Performance Assessment Verification Test***
~~PNL~~	~~Pacific Northwest Laboratory~~
QA	***quality assurance***
RH	remote-handled
RoR	***Rest of Repository***
SMC	***Salado Mass Concrete***
SNL	Sandia National Laboratories
SSBI	Small-Scale Brine Inflow
SWCF	Sandia National Laboratories WIPP Central Files
TDEM	Time Domain ElectroMagnetic
TRU	transuranic
~~USGS~~	~~United States Geological Survey~~
WIPP	Waste Isolation Pilot Plant
WQSP	Water Quality Sampling Program

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MASS-1.*0* INTRODUCTION

This ~~appendix~~ ***attachment*** presents supplementary information ***to Appendix PA*** regarding the assumptions, simplifications, or approximations used in the models of ***the first recertification*** ~~this~~ performance assessment ***(PA)*** of the Waste Isolation Pilot Plant (WIPP). ~~I~~***Withi***n ~~any topic area in~~ this ~~appendix~~***attachment***, relevant issues in the formulation or development of the various types of models (for example, conceptual, mathematical, numerical, or computer code) used for the topic ~~may be~~***are*** discussed~~.~~***, and references to relevant historical information are included where appropriate.*** ~~Because extensive discussion of computer codes *per se* is presented in stand-alone appendices, there is redundancy between portions of this appendix and other parts of this application. Additionally, where assumptions, simplifications, or approximations are implemented by way of a choice of the value of a parameter, there may be redundancy in this appendix with Appendix PAR.~~

~~Several types of information are presented in this appendix, including memoranda prepared during development of the performance assessment by the U.S. Department of Energy (DOE) personnel and documents associated with modeling assumptions tested during development of the performance assessment process. These are included as attachments in this appendix. These attachments are also maintained as project records in the Sandia National Laboratories (SNL) WIPP Central Files (SWCF).~~

Section MASS-2.***0*** contains a ***summary of changes in the PA*** ~~performance assessment~~ ***since the Compliance Certification Application (CCA).*** ~~historical perspective of the development of the concepts since 1975 about future WIPP performance. The remainder of this appendix is arranged to provide topical information on the major physical processes and systems introduced in Chapter 6.0 (Section 6.4) and modeled in the performance assessment.~~ Section MASS-3.***0 includes*** ~~begins this topical piece with~~ a discussion of general modeling assumptions applicable to the disposal system as a whole, including a table of assumptions made in ~~performance assessment~~ ***PA*** models, with cross-references. ~~In some topical discussions, the information relevant to a particular model is more appropriately included in a different appendix. Where this occurs, the reader is referred to the appendix that contains the relevant information.~~ ***The remainder of this attachment discusses assumptions specific to the first recertification PA conceptual models. Historical development of the WIPP conceptual models that led to the PA used in the CCA is documented in CCA Appendix MASS-2.0.***

MASS-2.*0* ~~HISTORICAL DEVELOPMENT OF WIPP CONCEPTUAL MODELS~~ *SUMMARY OF CHANGES IN PERFORMANCE ASSESSMENT*

Since the CCA, several ~~C~~***c***oncepts about the processes important to the performance of the WIPP have changed***. Additionally, ongoing confirmatory experiments, monitoring results, and operational practices have generated information relevant to the conceptual models for the WIPP PA and provide additional support to the conceptual basis of the PA.*** ~~since the DOE's inception, as the DOE and its predecessor agencies refined knowledge and understanding of features of the site and the processes and events that might occur there. Although the understanding of the WIPP site has continuously evolved since the early 1970s, the fundamental conceptual models that shaped projections of the WIPP's performance underwent major~~

~~refinement three times: in the mid-1970s during site selection; in the late 1970s during surface-based site characterization; and again in the mid-to-late 1980s. Since the late 1980s, the fundamental conceptual model has not changed in any major way. Experimental activities since the late 1980s have led to the level of understanding necessary for quantitative, probabilistic performance assessments. This section describes the evolution of the DOE's understanding of the processes and events of importance at the WIPP.~~

~~Techniques used to evaluate the consequences of radionuclide release from the repository have also changed. Changing the methods used to address the consequences of radionuclide exposure pathways has affected both the types of computational modeling used to evaluate performance and the understanding of the relative importance of the many physical properties of the disposal system. Until 1985, when the U.S. Environmental Protection Agency (EPA) promulgated its radiation protection standard for the management and disposal of spent nuclear fuel, high-level and transuranic wastes, 40 CFR Part 191, the consequences of release were primarily evaluated in terms of human exposure to radionuclides that had reached the biosphere by some mechanism, rather than in terms of any specific or quantitative release criterion. Contaminant transport in the geosphere was not regarded as a problem if humans were not exposed. Two principle pathways were of concern. Direct releases to the surface from a borehole could expose drillers and hypothetical future residents of the region who consumed livestock that grazed nearby. Individuals could also be exposed by drinking water from a contaminated source or by eating livestock watered at a contaminated stock pond. For example, the hypothetical exposed person was someone who drank water and ate fish from the Pecos River near Malaga Bend, a discharge point for contaminated groundwater from the Rustler (DOE 1980, 9 – 128, K23 – K24). (The release of contaminated Rustler groundwater at Malaga Bend is no longer considered plausible.) The consequences of release by diverse transport pathways were treated deterministically and individually. The time period considered for evaluating the effectiveness of the WIPP was usually about a quarter of a million years, roughly ten half-lives of ^{239}Pu, although this time frame was not specified by regulations.~~

~~40 CFR Part 191, promulgated in 1985, set release limits at defined boundaries. Therefore, determining possible contamination of areas far from the repository was no longer an objective of consequence modeling. Instead, quantities of actinides released from the disposal system, a defined volume, became the primary measure for assessing performance, although dose calculations to humans were still of interest to many groups and required for certain regulatory criteria. The probabilistic methodology suggested in 40 CFR Part 191 led to an appreciation of the possible interactions among multiple boreholes, assessment of the probabilities of defined events, and formal assessment of the performance impact of uncertainty in estimates of physical quantities. The standard also established a regulatory time period, during which actinide transport and system performance must be modeled. The EPA has become increasingly prescriptive about how the DOE should incorporate the uncertainty associated with projecting human actions into the future (for example, 40 CFR Parts 191 and 194, and the Compliance Application Guidance). In addition, expectations about the quantity and quality of supporting information used to support analyses of repository performance have gradually escalated.~~

~~Interactions between the DOE and external groups have played an important role in developing the current understanding of the disposal system performance. Interactions with the National Academy of Sciences (NAS) and interactions with the Environmental Evaluation Group (EEG)~~

~~have been the most important of these. Interactions with the state of New Mexico and with the EPA have also contributed. At various times through the years, the DOE has convened expert panels and working groups to obtain advice on certain issues; for example, an expert working group met for many years to advise on the treatment of uncertainty in characterizing the Culebra (Zimmerman and Gallegos 1993).~~

~~MASS.2.1 Conceptual Models Used During Site Selection (1975-1976)~~

~~The Oak Ridge National Laboratory (ORNL) selected the site for the WIPP in the early 1970s. At that time, the concept of long-term performance of the WIPP was based on an understanding that bedded salt deposits were dry, natural creep of the salt would encapsulate waste, salt had good heat-dissipation properties, and the northern Delaware Basin had predictable geology that was amenable both to repository construction and to predictions of performance. Site-selection criteria were strongly influenced by experience at the abandoned bedded-salt site near Lyons, Kansas, and consequently focused strongly on isolating the repository from potential breach mechanisms associated with resource exploitation and dissolution. Accordingly, buffer zones of two miles between the site and existing deep boreholes and of five miles between the site and any existing potash mines were established as criteria for siting, and interest in fluid flow in aquifers and abandoned boreholes was chiefly related to its potential for dissolving salt in the Salado Formation.~~

~~During site selection in the early 1970s, several ideas about the Salado and processes associated with radioactive waste disposal in it were accepted. The formation was known to contain anhydrite layers; the DOE wanted to choose a repository horizon without anhydrite beds in close proximity because they would interfere with creep and waste encapsulation. Project staff recognized that a disturbed rock zone (DRZ) would develop around the repository; but because of salt creep, the long-term effects of the DRZ were assumed to be negligible as the waste was encapsulated and the disturbed salt healed (that is, as its properties became similar once again to those of intact salt). The generation of gas by microbial degradation of waste constituents was recognized as a possible pressure-building mechanism. Because the Salado was thought to be dry, corrosion of steel in the waste was not considered to be important. It was known that intragranular brine inclusions could migrate toward waste as a result of the thermal effects of heat-emitting waste. This possibility for brine migration was of considerable concern because at the time it was intended that the WIPP would have two excavations for waste disposal: one at a shallower horizon for relatively cold transuranic (TRU) waste and one at a deeper horizon for heat-emitting spent nuclear fuel.~~

~~The ORNL identified a candidate site northeast of the present WIPP site in 1974. As discussed in Chapter 2.0 and Appendix GCR, drilling of U.S. Energy Research and Development Administration (ERDA)-6 in 1974 at that site revealed steeply dipping beds, missing units, and brine containing hydrogen sulfide near the deeper planned repository depths. The dipping beds and missing units indicated that a level, minable repository horizon free of anhydrite could not be expected. Hydrogen sulfide in the brine posed a potential hazard to mine workers. Thus, the discovery of the deformed beds and associated brine at the ORNL site changed the concept of uniform evaporite stratigraphy throughout the northern Delaware basin.~~

The ORNL site was deemed unacceptable, and a search for a new site with acceptable conditions was initiated in late 1975 (Delacroix 1977). The new search was conducted by SNL. SNL used selection criteria similar to ORNL's. The present site was identified in December 1975. Examination of petroleum exploration data, primarily seismic reflection surveys, indicated that deformation was limited largely to a zone paralleling the buried Capitan reef. A region in which Castile deformation is absent was identified and borehole ERDA-9 was drilled through the Salado near the center of the proposed site, confirming that its beds were flat-lying and that no brine was present in it or immediately below the potential repository elevations. Consequently, because the site satisfied this and other criteria, it was accepted as suitable in 1976, and site characterization began.

At the end of site selection and with the current site identified, the following concepts were accepted by the DOE and shaped thinking about the consequences of repository development:

- the Salado is dry, with no mobile intergranular liquid,
- intragranular fluid inclusions could migrate in thermal fields,
- gas could be generated by microbial action,
- salt would creep and encapsulate waste,
- there are deformed areas and brine-producing areas in the Delaware Basin evaporites, but the present site was free of deformation and brine at the potential repository horizons, and
- natural dissolution fronts would not threaten the repository, as a result of either vertical or lateral dissolution, for more than 250,000 years.

MASS.2.2 Conceptual Models Developed During Site Characterization and Repository Design (1976-1981)

Experimental activities conducted at the site immediately after site selection focused on characterizing the encapsulation properties of the Salado, the migration of intragranular brine in a thermal gradient, microbial gas generation, and the hydrologic properties of the units above the Salado.

After site selection, interest in fluid flow in water-bearing units of the area shifted from its effects on dissolution to the role of these units as potential pathways for radionuclide release. The Magenta and Culebra Members of the Rustler Formation and the Rustler-Salado contact zone were recognized from regional experience to be potential pathways. At the time, the relative importance of these units was unknown, so the first tests targeted all three. The Rustler-Salado contact was confirmed to be transmissive in Nash Draw but did not yield significant quantities of water at the site and did not represent a significant pathway for fluid movement for either radionuclide transport or dissolution. The Culebra was more transmissive than the Magenta, and the transmissivities of these units varied by several orders of magnitude. In time, characterization of groundwater pathways for radionuclide release became the principal characterization activity pursued at the WIPP site.

~~The hydrologic properties of the Salado were characterized by surface testing (drill-stem tests) during this period. These tests indicated measurable permeabilities over substantial thicknesses of the Salado, suggesting that the permeability of the Salado was sufficiently high that gas generated by microbial action would dissipate into the rock without reaching high pressure. Accordingly, the program to characterize gas generation, which had been progressing through the late 1970s, was canceled.~~

~~Many repository breach mechanisms by natural processes were postulated during this period, and investigations began to evaluate their likelihood and consequences. These investigations examined volcanism, tectonism, karst hydrology, deep dissolution, and other processes. In time, all such naturally occurring processes for breaching the repository were resolved as not likely to occur or not likely to occur in a manner that would impair WIPP performance.~~

~~MASS.2.3 Repository Design~~

~~The design of the repository — the dimensions and geometry of the rooms, pillars, and accessways — was conducted by Bechtel, Inc., in the late 1970s. The design sought to ensure long-term encapsulation of the waste by salt creep and to provide enough volume to dispose of the projected 6.2 million cubic feet (176,000 cubic meters) of waste. Given these performance criteria, the physical dimensions of the repository were determined with primary consideration given to mine safety during waste-disposal operations. Because the repository was designed prior to underground access, the basis for the design drew on experience gained from potash mines in the Delaware Basin.~~

~~The initial repository design placed the shafts at the south end of the repository, an area for experimental activities north of the shafts, and the waste-disposal region north of the experimental area. From early on, the DOE viewed the WIPP as a research and developmental facility that would conduct experiments that were of interest to a wide variety of disposal programs and concepts. Accordingly, the original purpose of the experimental area was to house experiments to support development of models of rock mechanics and salt creep, experiments on seal behavior, and experiments of interest to high-level waste disposal concepts, such as canister design and fluid-inclusion brine movement. It was not intended at first that the experimental region would support studies of phenomena that had been previously characterized from the surface, such as the permeability of the Salado.~~

~~The repository design did not initially include constructed barriers to separate the waste into modules. Early discussions with the NAS oversight panel led to concern that fire in combustible portions of the waste could pose a hazard to mine workers. Modularization of the waste was proposed to enhance mine safety. Because constructing closures is expensive and time-consuming, separating waste at the panel scale was considered the best of several options for balancing concerns about safety, cost, and mine operations.~~

~~In November 1981, the WIPP-12 borehole was deepened into the Castile and encountered large quantities of brine that flowed freely into the borehole and to the surface. The discovery of a Castile brine reservoir at WIPP-12 prompted the rotation of the waste panels from their planned location north of the experimental area to south of the shafts, the current configuration, and eventually led to a geophysical program in the 1980s to investigate the possibility of brine~~

reservoirs under the panels. Both the DOE and the EEG conducted consequence analyses of a drilling encounter with a brine reservoir like that at WIPP-12 and concluded that the health consequences were minor (Woolfolk 1982; Channell 1982).

In 1980, Congressional legislation limited the WIPP to the disposal of TRU waste, and plans for a spent-fuel disposal level in the Infra-Cowden salt near the base of the Salado were abandoned. Because TRU waste generates relatively little heat, migration of brine in fluid inclusions was of little concern for the WIPP after 1980, although tests were conducted of this phenomenon because of continued interest in high-level-waste disposal in salt beds elsewhere.

Thus prior to underground access at the WIPP in the early 1980s, several conceptual models shaped the thinking about the performance of the WIPP repository:

- the Salado is dry with no mobile intergranular liquid,
- intergranular fluid inclusions are unimportant,
- the Salado has permeability high enough that gas generated by microbial action will dissipate, and pressure will not build up,
- fluid flow and transport of radionuclides in Salado are negligible,
- natural processes are not likely to release radionuclides,
- the Culebra is the most important unit above the Salado,
- the Culebra hydrology is relatively simple,
- based on available batch K_d measurements and the assumption of porous-medium flow, retardation in Culebra is assumed, and
- WIPP-12 leads to rotation of panels away from encountered brine reservoir.

MASS.2.4 Conceptual Models Developed During Site Characterization and Development (1982 – Present)

The repository horizon was selected in 1982 after the initial shaft was sunk and after design of the repository had been established. The horizon was selected based on the preliminary design of the repository, salt thickness above and below the excavations, and ease of mining. The DOE wanted (a) the mine to be at least 300 feet (91 meters) below the McNutt Potash Zone (hereafter referred to as McNutt) to provide isolation from possible mining, (b) anhydrite bed or clay seams within the back (roof) to be at least 2 to 3 feet (0.6 to 0.9 meters) above the repository to reduce the possibility of roof fall, and (c) the mine to be as shallow as possible to minimize mining costs. The horizon selected between Marker Bed (MB) 138 and MB139 was deemed to best satisfy all of these criteria.

Experiments to investigate rock mechanics and salt creep were started in the initial underground excavations. Some brine was observed seeping into the repository from boreholes drilled upward into the back and collected in downward boreholes. Some brine was also observed on some freshly excavated surfaces. These observations led to significant changes in the conceptual models of WIPP performance.

The concern was raised that the waste would not become encapsulated in a solid mass by salt creep, because brine that had seeped in would impede such consolidation. Information about the rate of brine flow showed that concerns about the waste becoming fluidized were unrealistic because consolidation to a sufficiently low porosity would occur before significant amounts of brine could accumulate. However, a new series of tests was executed to validate beliefs about the hydraulic properties of the Salado that had been based on surface-based testing conducted in the late 1970s. This series of tests included the Small-Scale Brine Inflow, Brine Sampling and Evaluation Program (BSEP), Room Q, in-situ permeability tests, and laboratory flow tests. Some of these test programs continued until their conclusion in 1995.

The in-situ permeability tests showed that intergranular fluids were involved in flow and also demonstrated that the drill-stem tests conducted in the 1970s had overestimated the permeability of the Salado. These results led to the realization in the late 1980s that gas dissipation in the Salado would not be sufficient to avoid the potential for high pressures. Brine seepage into the repository raised the possibility of gas generation by corrosion of steel in addition to microbial gas generation. A new program to characterize gas generation began in the late 1980s.

Because of gas generation and low permeabilities in the far-field Salado, it was thought that high pressure in the repository could induce the Salado to fracture. This topic had been of concern in the 1970s when microbial gas generation was investigated. The renewed concern about gas generation led to a program to investigate hydrofracturing of the Salado interbeds by high pressure, and eventually to the adoption of a fracturing model in performance assessment.

Inadvertent penetration of the repository by deep drilling and the resultant release of radionuclides directly to the surface were treated deterministically in early evaluations of long-term performance. The promulgation of 40 CFR Part 191 made it necessary to consider the possibility of multiple boreholes and their interactions. The combination of brine saturation in the repository and possible high gas pressures led eventually to two new postulated mechanisms for release to the surface — gas spall (release of fine particulates caused by high gas pressures and flows from the waste to the penetrating borehole) and direct brine release to the surface during drilling — in addition to the cuttings and cavings releases that had been modeled previously.

Actinide solubilities were not considered important until the mid-to-late 1980s. Before this time, the DOE's expectation that the repository would be dry made aqueous concentrations seem unimportant. From early on, the DOE had considered adding getters (materials that act to remove radionuclides) to the repository, not so much to control actinide mobility as to assure performance (for example, Tyler et al. 1988). From the mid-to-late 1980s, however, the importance of actinide solubilities has been increasingly recognized in conjunction with the importance of release pathways involving fluid flow from the repository. Direct control of repository chemistry is more effective in controlling actinide solubilities than getters.

Transport of actinides in colloidal forms was recognized as potentially important by the late 1980s, but, because of lack of understanding, no allowance for the possible impact of actinide transport was made in the ranges chosen for actinide solubilities in early performance assessments. The effect of transport of actinides in colloidal forms was not explicitly modeled until the calculations for this application.

From the time of the initial conceptual design and the 1980 Final Environmental Impact Statement (FEIS) (DOE 1980), it was assumed that backfill would be emplaced in the repository to help fill the void space and reduce the magnitude of subsidence in overlying units, in addition to eliminating any potential risk of underground fire propagation. The WIPP Final Safety Analysis Report (DOE 1990) showed that there was no significant chance of fire propagation in the waste disposal region even in the absence of backfill. The Backfill Engineering Analysis Report (Westinghouse Electric Corporation, 1996) showed that addition of backfill would have negligible impact on the subsidence of overlying units. For a time, therefore, backfill was not considered as part of the baseline design for the repository. Recently, the addition of a carefully designed backfill to control chemical conditions in the repository has been shown to have significant benefit in assuring lower actinide solubilities.

Because of the possibility of high gas pressure in the repository and the associated possibility of fracturing of the Salado, it became apparent in the late 1980s that effective isolation of radionuclides from the anhydrite interbeds close to the repository could not be fully assured. Because the anhydrite interbeds were known to be relatively more permeable than the halite-rich horizons of the Salado, recognizing that the DRZ was not likely to heal effectively increased the potential importance of interbeds passing through the DRZ with respect to fluid flow in the Salado.

Panel closures were designed to isolate panels from each other during waste operations. For a time, in recognition of the concept that DRZ healing could not be relied upon to isolate interbeds from the repository and that fluids might flow around panel closures, these closures were essentially assumed not to exist for evaluations of long-term performance. This treatment was unrealistic, however, and the more reasonable idea that panel closures should be modeled with properties similar to those assigned to the imperfectly healed DRZ emerged.

The conceptual design of shaft seals evolved during the 1980s. The long-term ability of the shaft seals to isolate the repository from overlying units had been credited to a salt component to be emplaced throughout much of the Salado. The salt-based component would consolidate under the pressure of salt creep and, over a period of a hundred to several hundred years, would develop properties similar to that of intact salt. However, control of brine flow to the salt seal from upper units was of concern because significant volumes of brine could delay or even prevent creep consolidation of the long-term seal components of crushed salt. The early concepts of shaft construction, which used a concrete and concrete-grout plug to protect the salt component, were not thought to be robust enough to control downward brine flow and, possibly in the long term, might be susceptible to damage by the flow. This concern led to a design and testing program to develop the present shaft seal concept, which is based on the principle that multiple components and multiple materials provide demonstrable protection of long-term components from downward brine flow and support a high level of confidence in the expected behavior of shaft seals.

Test programs in the units above the Salado have been in progress continuously since site selection. The preeminent importance of the Culebra as a lateral pathway for transport has been recognized by the DOE. The Rustler and Salado contact was demonstrated to be unimportant, and the Magenta was demonstrated to have generally lower conductivity than the Culebra and not to have hydraulically significant fractures that could channel flow. Although the Rustler was characterized to some extent throughout its thickness, in the 1980s the interest focused on the Culebra. Transport in the Culebra has been demonstrated to be controlled by the variation in hydraulic conductivity and by interaction between flow in fractures and flow in matrix. Increasingly complex tests were conducted to characterize the Culebra, including multi-well tracer tests and regional pumping tests, culminating in the recent seven-well tracer test conducted at H-19, multiwell retesting at H-11, and distinctive single-well injection and withdrawal tests at both H-19 and H-11. Testing at these localities provided new, high-quality test results at two relatively high-permeability locations in the Culebra. Increasingly complex modeling techniques were used to represent the characterized variability and residual uncertainty in the transmissivity of the Culebra, assisted by review and advice from the Geostatistics Expert Group, a panel convened by the DOE, and INTRAVAL, an international model validation review group. Effective chemical and physical retardation was no longer assumed but became the subject of study, and by the early 1990s several alternative conceptual models had been advanced and were implemented in the preliminary performance assessments (WIPP Performance Assessment Department 1993, 8-27 to 8-56). One of these has since been identified as superior to the others (see Section MASS.15).

In the Dewey Lake, above the Rustler, boreholes occasionally produce groundwater but, because it had long been assumed that groundwater in the Dewey Lake is in discontinuous lenses and that regional flow does not occur, characterizing groundwater in the Dewey Lake was a low priority for the DOE. When performance assessments in 1994 showed that long-term releases to the Dewey Lake are unlikely because the Culebra captures all fluids moving upward through the Rustler in a borehole, further characterization of the Dewey Lake was perceived as unimportant. Recently, the DOE has recognized that a continuous water table may exist in the Dewey Lake, but it is observed only in areas where permeabilities are relatively higher than average. Nevertheless, if releases into the Dewey Lake occur, they will be of little consequence, because, as a red bed, the Dewey Lake has a uniformly distributed and large sorption capacity as the result of the widespread occurrence of both hydrated iron oxides and clays.

In the Castile, geophysical techniques were used to help resolve whether brine reservoirs like that encountered at WIPP-12 might exist under the waste panels. In the late 1980s, these techniques indicated a zone of lower resistivity that can be interpreted as brine. This zone exists under a portion of the waste disposal area.

In addition to experimental programs, the development of probabilistic performance assessments for the WIPP also led to a considerable effort to characterize the consequences of combinations of events and processes. One notable development was the identification of the need to model the effects of multiple intrusions into the repository, some of which might penetrate brine reservoirs, and the possible interactions among these intrusions in a partially saturated repository. This development led to the identification of the scenarios currently in use.

~~Thus, by the late 1980s, the conceptual model for the disposal system had changed considerably from that of the late 1970s to mid-1980s. Rather than a fairly simple repository horizon that encapsulated waste rapidly and was thereafter relatively stable, as envisioned through 1985, the first WIPP preliminary performance assessment in 1989 recognized that the long-term conditions in the disposal system depended critically on the interplay between various natural, excavation-induced, and waste-related processes, and the final condition depended closely on the relative rates of these processes. Although some changes have occurred since 1989 — for example, uncertainty about many aspects of the disposal system has been substantially reduced through experimental programs and some new release processes have been identified and incorporated — the overall conceptual model recognized in the late 1980s remains valid today:~~

- ~~the waste horizon is not effectively isolated from nearby interbeds,~~
- ~~the repository is partially to fully saturated with liquid,~~
- ~~gas generation is closely linked to other processes,~~
- ~~creep closure occurs but does not assure complete consolidation,~~
- ~~brine inflow from the Salado is likely,~~
- ~~high gas pressures in the repository could induce fracturing of Salado interbeds,~~
- ~~actinide solubilities and colloid actinides are important,~~
- ~~borehole-repository-brine reservoir intersections are possible,~~
- ~~multiple intrusions allow the possibility of cross-borehole flow,~~
- ~~the Culebra is the most transmissive upper unit, and releases through other units are unlikely, and~~
- ~~Culebra transport is complex, fractures are important, and retardation is sensitive.~~

~~This list of the major concepts developed in the late 1980s has driven the selection of subsequent experimental programs and determined the types of modeling done in performance assessment from 1989 onward. Since 1989, details have changed, but the overall concept of long-term performance has remained stable. The models described in Chapter 6.0 (Section 6.4) of this application and further described in this appendix are based on this overall conceptual understanding of disposal system interactions.~~

Changes that have occurred since the 1996 PA and new information that may be important to PA are as follows:

1. ***Features, events and processes (FEPs) assessment***
   A. ***Inclusion of organic ligands in solubility calculations***

2. Monitoring

A. Changes resulting from Culebra water level investigations

B. Drilling rate parameter change

C. Changes in Borehole plugging configuration probabilities

3. Experimental Activities

A. Magnesium-oxide investigations

B. Changes resulting from actinide investigations

4. PA Models and Systems

A. Administrative hardware and software updates

B. Conceptual model changes

i. Panels closures

ii. Simplification of shafts

iii. Grid refinements

iv. North and South Rest of Repository (RoR)

C. Spallings

D. Recalculation of Culebra T-fields

E. Performance Assessment Verification Test (PAVT) Baseline

5. Operational Considerations

A. WIPP horizon moved up to Clay Seam G

B. Waste inventory update

C. Evaluation of waste structural impacts, emplacement, and homogeneity

A summary of each change is presented in this section. References to appropriate sections of this attachment are provided for those changes that impact modeling assumptions. Additional references are provided to other areas of the Compliance Recertification Application (CRA) discussing change implementation.

MASS-2.1 Features, Events, and Processes Assessment

Based on the PA methodology for WIPP (see Section 6.2), FEPs are important elements to help develop the conceptual models and modeling assumptions represented in PAs. The process used to develop and screen FEPs is outlined in Section 6.2. The results of the CCA FEPs screening was documented in CCA Appendix SCR. For the CRA, a reassessment of the baseline PA FEPs was conducted to determine if changes in WIPP activities and conditions changed the original FEPs descriptions, basis, or screening decisions. This assessment also determined if additional FEPs should be included in the CRA baseline. The reassessment results are documented in SNL (2003a) and have been used to develop Appendix PA, Attachment SCR. Changes to the FEPs' baseline include combining similar FEPs and deleting redundant or inclusive FEPs, separating general FEPs into more descriptive FEPs, and FEP screening decision changes.

MASS-2.2 Monitoring

Monitoring activities have continued since the certification of WIPP. These activities are used to validate assumptions and PA parameters, and also to detect substantial and detrimental

deviation from expected repository performance. Monitoring, as discussed here, applies to the assurance requirement of 40 CFR §191.14(b) and the monitoring criteria at 40 CFR §194.42. Appendix MON details the monitoring program that meets these requirements. The monitoring program has led to three changes:

- *Culebra water levels at some wells have exceeded the ranges used in the CCA steady-state T-field calibrations,*
- *The drilling rate for deep boreholes has increased since 1996, and*
- *The probabilities for borehole plug configurations have changed slightly since 1996.*

The impacts and implementation of the new Culebra data are discussed in Section 2.2.1.4.1.2. and Appendix PA, Attachment TFIELD (see also MASS-2.4.2).

In the 2004 PA, two parameters have changed; the drilling rate and the probabilities for borehole plugging. The drilling rate for boreholes is discussed in Sections 6.0.2.3, 6.2.5.2; and Appendix DATA (Section DATA-2.0 and Attachment A). The probability for borehole plugging configurations is discussed in Section 6.4.7.2. No changes are necessary to modeling assumptions to account for these parameter changes.

MASS-2.3 Experimental Activities

The EPA requires the recertification documentation to include an update of "additional analyses and results of laboratory experiments conducted by the Department or its contractors as part of the WIPP program" (40 CFR 194.15(a)(3)). The following discusses analyses and experiments conducted to support compliance determinations. Only the analyses with conclusions relevant to this recertification are discussed here; all ongoing and supportive experiments are presented in biannual reports previously submitted to Environmental Protection Agency (EPA) (SNL 2001a, 2001b; SNL 2002a, 2002b; and SNL 2003b).

MASS-2.3.1 Magnesium-Oxide Investigations

Experiments have been preformed to support implementation of magnesium oxide (MgO) as an engineered barrier. These experiments investigate hydration and carbonization of MgO to confirm its ability to sequester carbon dioxide (CO_2), buffer brine pH, and subsequently reduce actinide solubilities in the repository. The conclusions drawn from these activities are described in Appendix BARRIERS. Specifically, the incorporation of MgO in PA has not changed from the 1996 PA.

MASS-2.3.2 Actinide Investigations

An Actinide Source Term Program (ASTP) has continued to investigate actinide (An) speciation and solubilities since the certification of WIPP. These investigations include work relating to organic ligands and colloid effects on solubilities, and the appropriateness of the use of the oxidation state analogy. These activities are described in SNL (2001a, 2001b; SNL 2002a, 2002b; and SNL 2003b). The conclusions drawn from these activities and the changes

to the 2004 PA are described in Appendix PA, Attachment SOTERM. Specifically, organic ligands are considered in the 2004 PA through the solubility calculations.

MASS-2.4 Performance Assessment Models and Systems

Changes have been made to the systems that are used to perform PAs. The PA hardware, operating systems, and parameter database were updated since the 1996 PA. These changes were necessary to replace obsolete hardware and operating systems and to increase PA capabilities. These changes were implemented and approved under applicable quality assurance (QA) requirements.

Additionally, conceptual model changes were necessary to implement new or different representations of physical systems in PA. Changes to conceptual models led to revised or replacement codes, which implement the conceptual models in PA. The following discusses these changes.

MASS-2.4.1 Administrative Hardware and Software Updates

The computer systems and operating systems have been upgraded since the 1996 PA because of increasing obsolescence of the operating system and hardware. New hardware is being used along with a newer operating system for the 2004 PA. All changes to these systems are performed under the appropriate QA program, and include testing, validation, and verification to ensure that there is no impact on PA implementation. A synopsis of the changes and references to the QA documentation are found in Long (2003).

MASS-2.4.2 Conceptual Model Changes

The certification decision by the EPA (1998a) included several conditions that the U.S. Department of Energy (DOE) was required to meet. In the first of these conditions, the EPA required the DOE to implement a specific design for the panel closure system (referred to as "Option D") and using Salado Mass Concrete (SMC). The DOE had included in the CCA four Options (A-D) for the panel closure design. The Option D design consisted of two components, a large concrete monolith and an explosion wall constructed of concrete blocks. The 1996 PA generically represented the closures in BRAGFLO and did not model a specific closure. The representation of the Option D closure has been incorporated into the BRAGFLO grid. The Option D closure modeling assumptions are discussed in Section MASS-19.0 and MASS-4.2. Panel closure implementation in PA is discussed in Appendix PA, Section PA-4.2.8.

To account for this design in PA, the conceptual model for Repository Fluid Flow, Disturbed Rock Zone (DRZ), and the Disposal System Geometry were revised and peer reviewed. Chapter 9 and Appendix PEER contains information on the conceptual model peer review. These conceptual models are implemented in BRAGFLO. See Section MASS-2.5.2 and MASS-4.2 for information on modeling assumptions and implementation of these conceptual models. Implementation of these conceptual model changes led to the following changes in BRAGFLO.

1. ***Implementation of Option D panel closures,***

2. Simplification of the shaft seal model,

3. Refinement of grid outside the excavated area to improve computational accuracy and efficiency,

4. Increased Segmentation in the North RoR and South RoR.

MASS-2.4.3 Spallings Model

An EPA guidance letter on recertification requested the DOE implement a new spallings conceptual model (EPA 2002). The original conceptual model for spallings was peer reviewed during the first certification, but was deemed inadequate by the peer review panel. The DOE later derived a method to represent spallings that was deemed conservative by the peer reviewers and was used by DOE in the 1996 PA. Since the CCA, however, a more appropriate and representative spallings model has been developed, peer reviewed, and implemented in the 2004 PA. Results of the peer review are found in Chapter 9 and Appendix PEER. Modeling assumptions concerning the Spallings model are detailed in Section MASS-16.1. Implementation of the spallings model is described in Appendix PA, Section PA-4.6.

No other conceptual models were revised for this recertification application.

MASS-2.4.4 Recalculation of Culebra T-fields

Water level rises in the Culebra have continued over recent years and the observed heads have exceeded the ranges of uncertainty established for the steady-state heads in many of the 32 wells used in the calibration of the transmissivity fields described in the CCA (SNL 2002b). Therefore, the DOE has recalculated T-Fields for the CRA using new Culebra data and geologic information (see Appendix PA, Attachment TFIELD; and Section 2.0). The DOE has implemented a program to identify other potential causes for the water-level rises (SNL 2003c).

MASS-2.4.5 Performance Assessment Verification Test Baseline

The EPA's PAVT parameters were incorporated into the 2004 PA parameter baseline (EPA 1998b, V-B-14). These parameters and a cross-reference of discussions concerning their incorporation into the 2004 PA are shown in Table 6-1.

MASS-2.5 Operational Considerations

Operational considerations are impacts to PA from changes to WIPP operations that the DOE has requested and the EPA has approved, or changes that have been mandated by the EPA.

MASS-2.5.1 Waste Isolation Pilot Plant Horizon Moved up to Clay Seam G

Operational changes to the repository design since the CCA include mining the repository horizon in the southern half of the waste panels at a different location than the northern half. Specifically, panels 3, 4, 5, 6, and 9 will be excavated at an elevation approximately 2.4 m above the level of panels 1, 2, 7, 8, and 10, and the operations and experimental areas. This

change in horizon will bring the roof of the raised rooms to the level of the Clay Seam G. The change is expected to improve roof conditions and enhance operations and mine safety. The DOE submitted a planned change request to the EPA that described the change and presented an argument that the change would have minimal impact on long-term repository performance (DOE 2000). The EPA responded to the change request in a letter (EPA 2000) in which they agreed with DOE that the effects to long-term performance would be minimal. Further investigations led DOE to determine that no changes to the 2004 PA models were necessary to account for this change. Section MASS-20.0 discusses the justification for this determination.

MASS-2.5.2 Waste Inventory Update

The waste inventory used in the CCA was based on information contained in the TWBIR (CCA Appendix BIR). No waste had been emplaced in the repository at that time. Since 1996, waste has been emplaced in the repository and better estimates have been made of the existing and projected waste streams at the generator sites. The new waste information has been updated in the 2004 PA to include the emplaced, currently stored, and projected waste streams. This information was collected in the TWBID, Rev 2, with specific WIPP information detailed in Appendix DATA, Attachment F. Inclusion of waste information in the 2004 PA is discussed in Appendix TRU WASTE.

MASS-2.5.3 Evaluation of Waste Structural Impacts, Emplacement, and Homogeneity

During the development of the CCA PA, the DOE choose to assume random placement of transuranic (TRU) waste in the WIPP, and developed conceptual and numerical models accordingly. The EPA reviewed these models and their results, and determined that DOE had modeled accurately random placement of waste in the disposal system. Since the time of the CCA, additional information about the waste and its emplacement has emerged and requires waste-related assumptions to be reevaluated. This evaluation is discussed in Section MASS-21.0.

MASS-3.*0* GENERAL ASSUMPTIONS IN PERFORMANCE ASSESSMENT MODELS

Several assumptions are applied generally to the disposal system through the conceptual and mathematical models implemented in the major computer codes used in this ~~performance assessment~~ *PA*. Several major assumptions are discussed here. A table of general assumptions is also presented in Section MASS-3.4.

MASS-3.1 Darcy's Law Applied ~~for~~ *to* Fluid Flow Calculated by BRAGFLO, ~~SECOFL2D~~*MODFLOW-2000*, and SECOTP2D

A mathematical relationship expressing the flux of fluid as a function of hydraulic head gradients applied, commonly known as Darcy's Law, is applied to geologic media for all fluid-flow calculations. For details about the specific formulation of Darcy's Law used, refer to Appendix *PA, Section PA-4.2* ~~BRAGFLO~~ for the disposal system ***and Section PA-4.8 for the Culebra.*** ~~modeling, and Appendices SECOFL2D and SECOTP2D for Culebra modeling.~~ Darcy's Law is not applied for flow up a borehole that is being drilled (see Section MASS-16.2***;*** and Section 6.4.7.1.1 for more discussion of this topic).

Darcy's Law generally applies for flow models if certain conditions are satisfied: (1) the flow occurs in a porous medium with interconnected porosity, (2) flow velocities are low enough that viscous forces dominate inertial forces, and (3) a threshold hydraulic gradient is exceeded. ***In CCA Appendix MASS, these conditions were shown to be valid for the WIPP PA.***

~~Hydraulic tests in the Salado (Beauheim et al. 1991; 1993) were carefully designed to limit the effects of outside influences on the tested interval and provide the best evidence for the controlling flow mechanism in the Salado. The tests influence rock as far as 33 feet (10 meters) from the test zone and are not thought to significantly alter the pretest conditions of most of the tested region. The stratigraphic intervals tested include halite (both pure and impure) and anhydrite with associated clay seams at distances from 3 to 75 feet (1 to 23 meters) from the repository. Because tests close to the repository are within the DRZ, tests farthest from the repository are considered more representative of undisturbed conditions.~~

~~The tests are interpreted using potentiometric flow models incorporating Darcy's Law. Successful interpretations using these models are obtained and indicate a continuous porous medium that can be hydraulically characterized with permeability, pore compressibility, and porosity parameters. Tests in pure halite yield ambiguous interpretations, indicating either very low permeability or no flow whatsoever (a potential violation of the applicability of Darcy's Law). However, the effects of the pure halite layers on the performance of the repository have been demonstrated to be small (see below). Thus, the regions of importance to the performance of the repository have been tested, appear to meet the criteria for Darcy flow, and can be assumed to behave as continuous porous media that obey Darcy's Law.~~

~~Bear (1972, 125) discusses the balance of viscous and inertial forces in fluid flow. The Reynold's number, Re, is the ratio of inertial to viscous forces. For porous media, Re is calculated as~~

$$Re = \frac{qd}{\nu},$$

~~where q is the specific discharge in units of length per time, d is some length dimension of the porous matrix, and ν is the kinematic viscosity of the fluid in units of length squared per time ($\nu = \mu/\rho$, where ρ is fluid density and μ is dynamic viscosity). In principle, d is related to the length of elementary channels in the porous medium. Because of the difficulty of establishing this length, however, it is customary to use some measure of the pore grain size for d. Alternatively, Collins (1961) suggests $d = (k/n)^2$, where k is permeability in units of length squared, and n is porosity. The upper limit for application of Darcy's Law is not exceeded if Re is less than some number between 1 and 10 (Bear 1972, 126).~~

~~The specific discharge above which the models of fluid flow might be invalid can be estimated for the WIPP. The maximum d in the BRAGFLO domain, by Collins' method, is approximately 2×10^{-4} centimeters (calculated for the waste disposal region, using an assumed permeability of 1×10^{-12} square meters = 1×10^{-8} square centimeters and an assumed porosity of 0.2). Salado~~

brine has a dynamic viscosity of 2.1×10^{-2} grams per centimeter per second; a density of 1.22 grams per cubic centimeter, for a kinematic viscosity of 0.017 grams per cubic centimeter per second. Taking Re equal to 1 as the critical indicator, the critical specific discharge is the ratio of v to d, and has a value approaching 100 centimeters per second. As all specific discharges of brine in the BRAGFLO model are significantly less than this value, viscous forces dominate brine flow in the model and the upper limit of the validity of Darcy's Law is not exceeded.

For gas in the WIPP, assumed to have the properties of hydrogen for this calculation, density is about 8.2×10^{-5} grams per cubic centimeter and dynamic viscosity is about 89.2×10^{-6} grams per centimeter per second, for a kinematic viscosity of about 1.1 square centimeter per second. The critical specific discharge for gas in the BRAGFLO model is greater than 5,000 centimeters per second. In WIPP simulations of gas flow, q for gas remains below this value, indicating that the upper limit for the validity of Darcy's Law for gas is not exceeded.

Bear (1972, 128) proposes that a minimum hydraulic gradient, the threshold hydraulic gradient, exists below which flow in porous media does not occur. The minimum gradient may be required to overcome countercurrents that may occur at very low velocities, or may be required to overcome the slight nonNewtonian behavior of the viscosity of water. In general, this behavior is evident in fine-grained, low permeability rock such as clay. Because the WIPP is situated in the low-permeability Salado, flow may not be able to occur through the Salado unless a minimum hydraulic gradient is exceeded. Testing for a minimum hydraulic gradient is extremely difficult, however, and therefore has not been attempted at the WIPP.

Except for pure halite, Salado intervals tested at the WIPP have responded to hydraulic testing, and test results can be interpreted to high certainty using models based on Darcy's Law without correcting for the existence of minimum hydraulic gradients. This is strong evidence that the standard Darcy's Law is applicable in these units. In hydraulic tests of the pure halite, no hydraulic response to induced pressure change in the test zone was observed. Two explanations are offered for the results observed during the test. Either (1) the pure halite has a permeability low enough that a hydraulic response could not be measured over the duration of the test, or (2) a high threshold gradient for fluid flow exists in pure halite and was not exceeded during the test in rock around the test interval.

Although the reason for the lack of response in pure halite during flow tests is not established conclusively, its behavior can be approximated in continuum models of fluid flow based on Darcy's Law by assigning it an extremely low permeability relative to other rocks units, which effectively prevents flow through the volume that represents pure halite. This technique assumes the gradients calculated during modeling in the pure halite interval will not exceed the threshold gradient for flow, if it exists. For performance assessment modeling, this assumption is sound given that relatively large gradients were imposed on the unit during hydraulic testing and did not induce flow. Christian-Frear and Webb (1996) analyzed the effects of the variation in lithologic types, including pure halite, in a model of the Salado surrounding the repository. In their study, they found that the hydrologic response of the Salado to the presence of the repository was adequately represented by the simplified stratigraphic representation that is implemented in BRAGFLO. Thus, even though the lack of hydraulic response in pure halite units is not conclusively explained, the hydraulic characterization of pure halite intervals is adequate for an accurate assessment of WIPP performance.

Darcy's Law assumes laminar flow, that is, there is no motion of the fluid at the fluid/solid interface. For liquids, it is reasonable to assume laminar flow under most conditions. For gases at low pressure, however, gas molecules near the solid interface may not have intimate contact with the solid and may have finite velocity, not necessarily zero. This effect, which results in additional flux of gas above that predicted by application of Darcy's Law, is known as the slip phenomenon, or Klinkenberg effect (Bear 1972, 128). A correction to Darcy's Law for the Klinkenberg effect is incorporated into the BRAGFLO model (see Appendix ***PA, Section PA-4.2).*** ~~BRAGFLO, Section 4.12, for additional details).~~

Darcy flow for one and two phases implies that values for certain parameters must be specified. Some principal parameters relate to the properties of the fluid, others to the rock. Fluid properties in the Darcy flow model used for the WIPP are its density, viscosity, and compressibility. Rock properties in Darcy flow models are porosity, permeability, and compressibility (pore, bulk, or rock). In BRAGFLO, other parameters are required to describe the interactions or interference between the two phases present in the model, gas and brine, because they can occupy the same pore space. In the WIPP application of Darcy flow models, compressibility of both the liquid and rock are related to porosity through a dependence on pressure. Fluid density, viscosity, and compressibility are functions of fluid composition, pressure, and temperature. In BRAGFLO, fluid viscosity is a function of pressure, but its density and compressibility are held constant. Fluid composition for the purposes of modeling flow and transport is assumed to be constant.

MASS-3.2 Hydrogen Gas as Surrogate for Waste-Generated Gas Physical Properties in BRAGFLO ***and DRSPALL***

Hydrogen gas is produced by the corrosion of steel in the repository by water or brine. As in the CCA, t~~T~~he gas phase in the BRAGFLO model is assigned the properties of hydrogen because hydrogen will, under most conditions reasonable for the WIPP, be the dominant component of the gas phase. ***The model for spallings, DRSPALL, also assigns physical properties of hydrogen to the gas phase. In the CCA, the effect of assuming flow of pure H_2 instead of a mixture of gases (including H_2, CO_2, H_2S, and CH_4), was shown to be minor relative to the permeability variations in the surrounding formations.***

~~Hydrogen gas is produced by the corrosion of steel in the repository by water or brine. Because of the surface area, the total mass of steel emplaced, and the quantity of brine that is reasonably expected to flow into the repository from the Salado, as much as 0.3×10^6 moles of hydrogen per year can be generated in the repository and 2×10^9 total moles of hydrogen (Wang 1995).~~

Other gases may be produced by processes occurring in the repository. If microbial degradation occurs, a significant amount of ***carbon dioxide (***CO_2***)*** and ***methane (***CH_4***)*** will be generated by microbial degradation of cellulosics, and, perhaps, plastics and rubbers in the waste. ***The*** CO_2 produced, however, will react with ***the magnesium-oxide (***MgO***)*** ~~backfill~~ ***engineered barrier*** and cementitious materials to form ~~$MgCO_3$~~ ***brucite ($Mg(OH)_2$)*** ~~and $CaCO_3$~~, ***hydromagnesite ($Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$), and calcite ($CaCO_3$)*** thus resulting in very low CO_2 fugacity in the repository. Although other gases exist in the disposal system, for BRAGFLO calculations it is assumed these gases are insignificant and are not included in the model.

With the average stoichiometry gas generation model, the total number of moles of gas generated will be the same whether the gas is considered to be pure H_2 or a mixture of several gases, because the generation of other gases is accounted for by specifying the stoichiometric factor y. Therefore, considering the moles of gas generated alone, the pressure buildup in the repository will be approximately the same, because the expected gases behave similarly to an ideal gas, even up to lithostatic pressures.

The effect of assuming pure H_2 instead of a mixture of gases (including H_2, CO_2, H_2S and CH_4) on flow behavior, and its resulting impact on the WIPP repository pressure is presented as follows:

Radial flow of a 100 percent saturated rock with nonideal gas is described by Darcy's Law (Amyx et al. 1960):

$$q_b = 1.988 \_ 10^{-5} \left[\frac{T_b z_b}{P_b} \frac{kh\left(P_e^2 - P_w^2\right)}{\mu_{avg} z_{avg} \ln\left(\frac{r_e}{r_w}\right)} \right], \qquad (2)$$

which can be rewritten:

$$P_e^2 - P_w^2 = \frac{q_b}{1.988 \_ 10^{-5}} \left[\frac{P_b}{T_b z_b} \frac{\mu_{avg} z_{avg} \ln\left(\frac{r_e}{r_w}\right)}{kh} \right], \qquad (3)$$

where:

q = gas flow rate, cubic feet per day at base (reference) conditions
T = temperature, K
P = pressure, pounds per square inch atmosphere
k = permeability, millidarcys
h = height, feet
μ = viscosity, centipoises
z = gas compressibility factor (a function of gas pressure and temperature)
r = radius, consistent units
e = external boundary (repository)
w = internal boundary (wellbore)
b = base or reference conditions for gas (temperature, pressure, compressibility factor)
avg = average properties between external and internal boundaries because u and z are functions of pressure which change with time.

This expression is very useful for looking at the relationships of gas properties (specifically μ and z [which is a function of the gas temperature and pressure]) and rock properties (namely k) on defining q and P.

In order to evaluate the effect of gas composition on q and P, a computer program developed by the National Institute of Standards and Technology (NIST) entitled SUPERTRAPP was used (NIST 1992). This computer program allows calculations of gas properties for 116 pure fluids and mixtures of up to 20 components for temperatures to 1,000 K and pressures to 300 megapascals. The computer program currently can evaluate hydrogen, CO_2, and water but does not have the capacity to evaluate brine (Friend and Huber 1994). ~~In analyzing gas flow, it is assumed that CH_4 will behave similarly to CO_2.~~ Because such small quantities of H_2S are anticipated at the WIPP, its impact will be neglected. ~~Therefore, for this evaluation only the impact of CO_2 is considered.~~

Figure MASS-1 shows the relationship between gas viscosity ***H_2-CO_2 mixtures*** for various mole fractions of H_2 at pressures of 7 megapascals and 15 megapascals as determined from SUPERTRAPP. The viscosity at 50 percent mole fraction H_2 is 2.3 times greater than for 100 percent mole fraction H_2. As shown in Equation ***(***2***)***, viscosity has an inverse relationship to flow rate and, as shown in Equation ***(***3***)***, a direct relationship to the square of the repository pressure. Hence viscosity differences that would result if gas properties other than those of hydrogen were incorporated would result in a decrease in flow rate and potentially higher pressures.

As shown in Figure MASS-2, the gas compressibility at 50 percent mole fraction H_2 is about 0.9 times that at 100 percent mole fraction H_2. Like viscosity, the gas compressibility factor is inversely related to flow rate and directly related to the square of the repository pressure. Hence changing composition from 100 percent to 50 percent H_2 would result in a slight increase in flow rate and a decrease in pressure. Therefore, the impact of variation in gas compressibility caused by composition is considered minor and so is neglected.

The viscosity and compressibility calculations described above for H_2-CO_2 mixtures were repeated for H_2-CH_4 mixtures for various mole fractions of H_2 at pressures of 7 MPa and 15 MPa (Kanney 2003). The variability of viscosity with the composition for the H_2-CH_4 mixtures is smaller than that observed for the H_2-CO_2 mixtures. For example, the gas viscosity of H_2-CH_4 at 50 percent mole fraction is only 1.6 times greater than that for 100 percent mole fraction H_2 at 15 MPa. The H_2-CH_4 mixtures are only slightly less compressible than the H_2-CO_2 mixtures. For example, the gas compressibility of H_2-CH_4 at 50 percent mole fraction is about 0.94 times that for 100 percent mole fraction H_2 at 15 MPa.

The absolute permeability of the surrounding formation plays a significant part with respect to both flow rate and pressure determinations. Because marker bed permeabilities range over four orders of magnitude (see Appendix PAR, ~~Parameter 20~~***Tables PAR-30 to PAR-32***), these primary flow pathways will have a greater influence on pressure and flow rate determinations compared to either uncertainty in viscosity or gas compressibility effects.

It should also be noted that the BRAGFLO code includes a pressure-induced fracture model that will limit pressure increases in the repository (Schreiber 1997). For example, at high repository pressures, the factor of 2.3 pressure increase calculated here using the simplified Darcy's Law model is unlikely to be seen in the BRAGFLO results, since fracturing will lead to increased permeability, effectively limiting pressure increases.

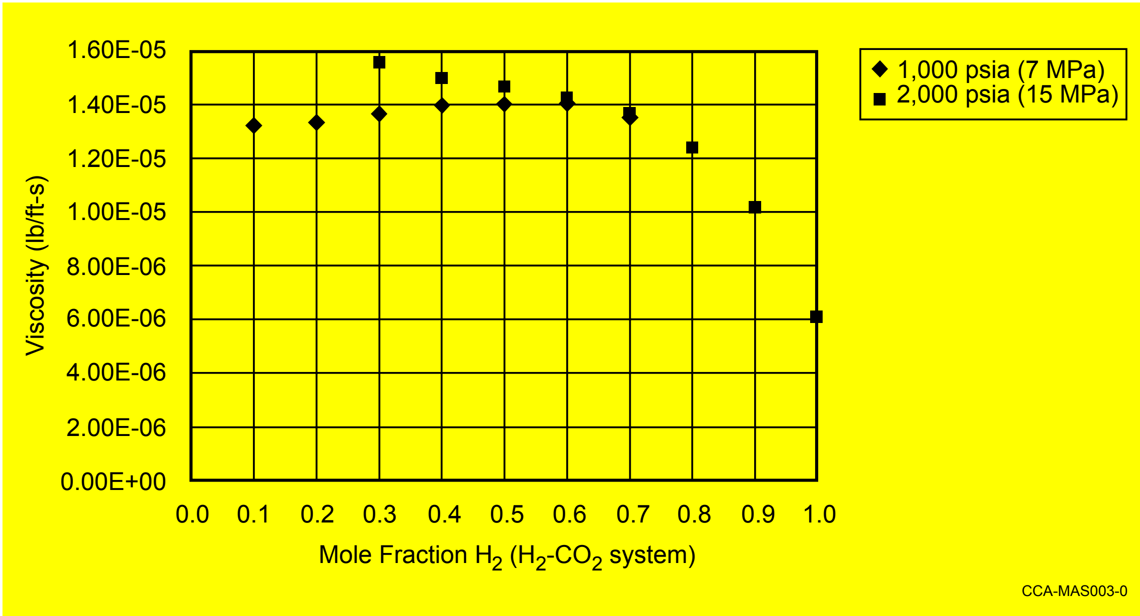

Figure MASS-1. Gas Viscosity as a Function of Mole Fraction H_2 at 7 Megapascals and 15 Megapascals Pressure

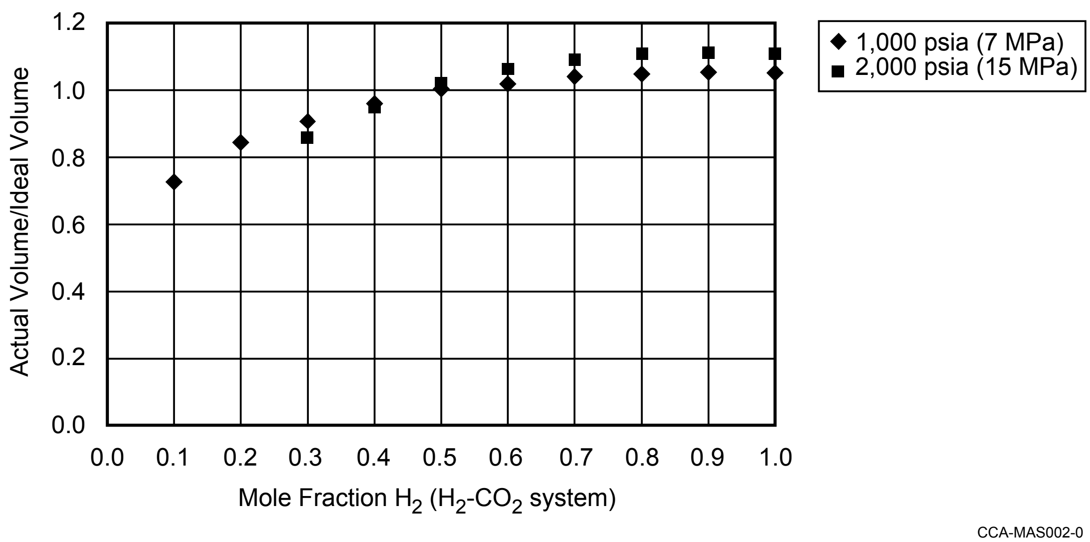

Figure MASS-2. Gas Compressibility as a Function of Mole Fraction H_2

MASS-3.3 Salado Brine as Surrogate for Liquid Phase Physical Properties in BRAGFLO

BRAGFLO models physical properties for all liquids as Salado brine properties. However, liquid in the modeled region may consist of (1) brine originally in the Salado, (2) liquid introduced in the excavation during construction, maintenance, and ventilation during the operational phase, (3) a very small amount of liquid introduced as a component of the waste, (4) liquid from overlying units, and (5) liquid from the Castile brine reservoir. However, for

BRAGFLO modeling it is assumed that the properties of all of these liquids are similar enough to Salado brine properties that the effect of variation in properties that may occur from liquids mixing is negligible. ***The variations in chemical properties of brine are accounted for as discussed in Section 6.4.3.4, and 6.4.3.5; and Appendix PA, Attachment SOTERM.*** ~~The properties required by BRAGFLO, and the subject of the discussion here, are density, viscosity, and compressibility.~~

~~Following repository closure, Salado brine will flow toward the repository at a rate that depends on the properties of the rock and brine, as well as hydraulic gradients. Brine flowing into the repository from the Salado is an important, sometimes dominant, source of liquid in the repository following closure. Because Salado brine is the only important source of brine that is present in all scenarios, it is assumed that the properties of brine important in the BRAGFLO model are the same as those of Salado brine.~~

~~During construction of the repository, water was spread for dust control. This water principally consisted of groundwater from the Culebra collected in the sumps and manufactured brine purchased from a local vendor. The physical properties of Salado brine as a surrogate for this Culebra brine are adequate because (1) the two brines have similar original physical properties, (2) the introduced brine will have equilibrated with liquid in the Salado and by dissolution, (3) some of the introduced liquid has evaporated, and (4) the volume introduced is relatively small.~~

~~Introduction of liquid through respiration in the repository is also considered insignificant. Because of the dry climate in the region, air drawn in from the surface and circulated through the repository is normally undersaturated in water vapor. In addition, the relative humidity of mine air is less than the equilibrium humidity of water in the mine environment. Thus, this liquid vapor remains in the vapor state until it is removed from the repository through forced circulation up the ventilation shaft.~~

~~The density difference among Salado brine, Castile brine, and brine from overlying units is the result of varying dissolved mineral content. Castile brine contains essentially sodium chloride (NaCl), while the Salado brine is saturated with approximately one-half sodium chloride and one-half magnesium chloride. Brine from overlying units is consistently fresher. Densities for WIPP brines were measured and reported by Brush (1990). The specific gravity of Salado and Castile brines are very similar and vary between 1.215 to 1.23 grams per cubic centimeter. Brines from the units above the Salado have lower specific gravity (for example, the specific gravity of Culebra brine is about 1.09 grams per cubic centimeter [WIPP Performance Assessment Division 1991]).~~

~~The viscosity of Salado brine is approximately 1.8×10^{-3} cp; for Culebra brine, the viscosity is approximately 1×10^{-3} cp (WIPP Performance Assessment Division 1991). Because of their similar specific gravity, it is expected that the viscosity of Castile and Salado brines is similar.~~

~~The ratio of density to viscosity appears in flow equations. The maximum difference of these is close to a factor of two for the three types of brines. Compressibilities range from approximately 2×10^{-10} per pascal for Culebra brine (for this discussion the range is assumed to be similar to that of water) to 2.5×10^{-10} per pascal for Salado brine and 9×10^{-10} per pascal for Castile brine (WIPP Performance Assessment Division 1991). The differences in the physical properties~~

~~among these brines are considered insignificant with regard to the position of complementary cumulative distribution functions (CCDFs) because the variability of these values is relatively small (factors of two or three, without considering blending effects of mixing), and CCDFs are typically plotted in log-log format with many log cycles. Therefore, these differences are assumed negligible in the performance assessment. (Note that variability in chemical properties of these brines is accounted for, as discussed in Chapter 6.0, Sections 6.4.3.4 and 6.4.3.5, and Appendix SOTERM, Section SOTERM.2.2.1.)~~

MASS-3.4 Table of General Modeling Assumptions

This section presents Table MASS-1, which lists modeling assumptions used in the ~~performance assessment~~ ***PA***. Table MASS-1 is a guide to general modeling assumptions used and provides some guidance for integrating the assumptions made with (a) the chapters or appendices in which they are discussed and (b) the code(s) that implement these assumptions.

The FEPs discussed in Appendix ~~SCR~~***PA, Attachment SCR*** that are relevant to the assumptions are also indicated. The final column in the table indicates whether the DOE considers the assumption described to be reasonable or conservative. As discussed in Section 6.5, the DOE has not attempted to bias the overall results of the performance assessment toward a conservative outcome. However, where data or models are infeasible to obtain, or where effects on performance are not expected to be significant enough to justify development of a more complicated model, the DOE has chosen to use conservative assumptions. The designator R (reasonable) in the final column indicates that the DOE considers the assumption to be reasonable based on WIPP-specific data or information, data and information considered analogous to the WIPP disposal system, expert judgment, or other reasoning. The designator C (conservative) indicates the DOE considers the assumption made may overestimate a process or effect that may contribute to releases to the accessible environment. The regulatory designator (Reg) indicates that the assumption is based on regulations in 40 CFR Part 191, criteria in 40 CFR Part 194, or other regulatory guidance.

MASS-4.*0* MODEL GEOMETRIES

This section presents supplementary information on the disposal system geometry. ~~presented in Chapter 6.0 (Section 6.4.2), as modeled by the code BRAGFLO, and the Culebra flow and transport geometries used, as modeled by the codes SECOFL2D and SECOTP2D.~~

MASS-4.1 Disposal System Geometry as Modeled in BRAGFLO

Overall, the conceptual model of the geometry of the disposal system is that the spatial effects of process interactions can be represented in two dimensions. The geometry used to represent the processes of long-term fluid flow in the Salado, flow between a borehole and overlying units, and flow within the repository (where processes coupled to fluid flow occur, such as creep closure and gas generation), is a vertical cross-section through the repository on a north-south axis. The dimension of this geometry in the direction perpendicular to the plane of the cross-section varies so that spatial effects of certain processes can be better represented, as discussed below.

Table MASS-1. General Modeling Assumptions

~~CCA~~***CRA*** Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
MASS-3.***0*** Some General Assumptions in Performance Assessment Models					
MASS-3.1 Darcy's Law Applied for Fluid Flow calculated by BRAGFLO, ~~SECOFL2D~~ ***MODFLOW-2000,*** and SECOTP2D					
	1	BRAGFLO ~~SECOFL2D~~ ***MODFLOW-2000***	Flow is governed by mass conservation and Darcy's Law in porous media. Flow is laminar and fluids are Newtonian.	Saturated groundwater flow ***(N23)*** Unsaturated groundwater flow ***(N24)*** Brine inflow ***(W40)***	R
	2	BRAGFLO	Two-phase flow in the porous media is by simultaneous immiscible displacement.	Fluid flow caused by gas production ***(W42)***	R
	3	BRAGFLO	The Brooks-Corey or Van Genuchten/Parker equations represent interaction between brine and gas.	Fluid flow caused by gas production ***(W42)***	R
	4	BRAGFLO	The Klinkenberg effect is included for flow of gases at low pressures.	Fluid flow caused by gas production ***(W42)***	R
	5	BRAGFLO	Threshold displacement pressure for flow of gas into brine is constant.	Fluid flow caused by gas production ***(W42)***	R
	6	BRAGFLO ~~SECOFL2D~~ ***MODFLOW-2000*** SECOTP2D	Fluid composition and compressibility are constant.	Saturated groundwater flow ***(N23)*** Fluid flow caused by gas production ***(W42)***	R
MASS-3.2 Hydrogen Gas as Surrogate for Waste-Generated Gas Physical Properties in BRAGFLO					
	7	BRAGFLO ***DRSPALL***	The gas phase is assigned the density and viscosity properties of hydrogen.	Fluid flow caused by gas production ***(W42)***	R
MASS-3.3 Salado Brine as Surrogate for Liquid Phase Physical Properties in BRAGFLO					
	8	BRAGFLO	All liquid physical properties are assigned the properties of Salado brine.	Saturated groundwater flow ***(N23)***	R
6.4.2 Model Geometries MASS-4.***0*** Model Geometries					
6.4.2.1 Disposal System Geometry MASS.4.1 Disposal System Geometry as Modeled in BRAGFLO					
		BRAGFLO	The disposal system is represented by a two-dimensional, north-south, vertical cross section.	Stratigraphy ***(N1)*** Physiography ***(N39)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~ *CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
		BRAGFLO	Flow in the disposal system is radially convergent or divergent centered on the repository, shaft, and borehole for disturbed performance.	Saturated groundwater flow ***(N23)*** Unsaturated groundwater flow ***(N24)***	R
		BRAGFLO	Variable dip in the Salado is approximated by a 1~~º~~ ***degree*** dip to the south.	Stratigraphy ***(N1)***	R
		BRAGFLO	Stratigraphical layers are parallel.	Stratigraphy ***(N1)***	R
		BRAGFLO	The stratigraphy consists of units above the Dewey Lake, the Dewey Lake, the Forty niner, the Magenta, the Tamarisk, the Culebra, the ~~Unnamed Lower Member~~ ***Los Medaños***, and the Salado (comprising impure halite, MB 138, anhydrites a and b [lumped together], and MB139). The dimensions of these units are constant. A Castile brine reservoir is included in all scenarios.	Stratigraphy ***(N1)***	R
6.4.2.2 Culebra Geometry MASS-4.3 Historical Context of Culebra Geometries as Modeled in ~~SECOFL2D~~***MODFLOW-2000*** and SECOTP2D					
		~~SECOFL2D~~ ***MODFLOW-2000*** SECOTP2D	The Culebra is represented by a two-dimensional, horizontal geometry for groundwater flow and radionuclide transport simulation.	Stratigraphy ***(N1)***	R
		~~SECOFL2D~~ ***MODFLOW 2000*** ~~GRASPINV~~ ***PEST***	Transmissivity varies spatially. There is no vertical flow to or from the Culebra.	Groundwater recharge (N54) Groundwater discharge (N53)	R
		SECOTP2D	The regional flow field provides boundary conditions for local transport calculations.	Advection ***(W90)***	R
6.4.3 The Repository MASS.5 BRAGFLO Geometry of the Repository					
		BRAGFLO	The repository comprises five regions ***separated by panel closures***: ~~a~~ ***the*** waste panel, ***a north RoR, a south RoR*** ~~the panel closures, the remainder of the panels~~ and the access drifts ***(separated by panel closures)***, the operations region, and the experimental region. Also, a single shaft region is modeled, and a borehole region is included for a	Disposal geometry ***(W1)***	R-C

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
			borehole that intersects the separate waste panel. The dimensions of these regions are constant ***(see Figure 6-14).***		
		BRAGFLO	Long-term flow up plugged and abandoned boreholes is modeled as if all intrusions occur into a downdip (southern) panel.	Disposal geometry ***(W1)***	C
		BRAGFLO	For each repository region the model geometry preserves design volume.	Disposal geometry ***(W1)***	R
		BRAGFLO	Pillars ~~and~~ individual drifts and rooms~~, and panel closures in the nine lumped panels,~~ are not modeled for long-term performance, and containers provide no barrier to fluid flow.	Disposal geometry ***(W1)***	C
		~~BRAGFLO~~	~~The distance from the south end of the modeled waste panel to the modeled shaft is the true distance from the south end of the waste disposal region to the waste handling shaft.~~	~~Disposal geometry~~	~~R~~
		BRAGFLO	Long-term flow is radial to and from the borehole that intersects the waste disposal panel during disturbed performance.	Waste-induced borehole flow ***(H32)***	R
		BRAGFLO	***DRZ provides a pathway to Marker Beds***		***R***
		BRAGFLO	***Grid and material properties are consistent with the Option D design***		***R***
		~~BRAGFLO~~	~~Panel closures are modeled with the same properties as the surrounding DRZ.~~	~~Disposal geometry~~	~~C~~
6.4.3.1 Creep Closure MASS-6***.0*** Creep Closure Appendix PORSURF					
		SANTOS	Creep closure is modeled using a two-dimensional model of a single room. Room interactions are insignificant.	Salt creep ***(W20)*** Changes in the stress field Excavation-induced changes in stress ***(W19)***	R
		SANTOS	Creep closure causes a decrease in room volume, which decreases waste porosity. The amount of creep closure is a function of time, gas pressure, and waste matrix strength.	Salt creep ***(W20)*** Changes in the stress field ***(W21)*** Consolidation of waste ***(W32)*** Pressurization ***(W26)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
		BRAGFLO	Porosity of operations and experimental areas is fixed at a value representative of consolidated material.	Salt creep ***(W20)***	R
6.4.3.2 Repository Fluid Flow MASS-7***.0*** Repository Fluid Flow					
		BRAGFLO	General assumptions 1 to 8.		See above
		BRAGFLO	The waste disposal region is assigned a constant permeability representative of average consolidated waste without backfill.	Saturated groundwater flow ***(N23)*** Unsaturated groundwater flow ***(N24)***	R
MASS-7.1 Flow Interactions with the Creep Closure Model					
		BRAGFLO	The experimental and operations regions are assigned a constant permeability representative of unconsolidated material and a constant porosity representative of consolidated material.	Saturated groundwater flow ***(N23)*** Unsaturated groundwater flow ***(N24)*** Salt creep ***(N20)***	R
MASS-7.2 Flow Interactions with the Gas Generation Model					
		BRAGFLO	For gas generation calculations, the effects of wicking are accounted for by assuming that brine in the repository contacts waste to an extent greater than that calculated by the Darcy flow model used.	Wicking ***(W41)***	R
6.4.3.3 Gas Generation MASS-8***.0*** Gas Generation Appendix ~~WCA~~ ***TRU WASTE***					
		BRAGFLO	Gas generation occurs by anoxic corrosion of steel containers, and Fe and Fe-base alloys in the waste, giving H_2, and microbial ~~degradation~~***consumption*** of cellulosics and, perhaps, plastics and rubbers, giving mainly CO_2 and CH_4. Radiolysis, oxic reactions, and other gas generation mechanisms are insignificant. Gas generation is calculated using the average - stoichiometry model, and is dependent on brine availability.	Container material inventory ***(W5)*** Waste inventory ***(W2)*** Degradation ***Consumption of*** ~~organic material CPR~~ ***(W44)*** Gases from metal corrosion ***(W49)***	R
		BRAGFLO	The anoxic corrosion rate is dependent on liquid saturation. Anoxic corrosion of steel continues until all the steel is consumed. Steel corrosion will not be passivated by	Brine inflow ***(W40)*** Gases from metal corrosion ***(W49)*** ~~Degradation~~ ***Consumption*** of organic	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~***CRA*** Section and Appendix	Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
		microbially-generated gases CO_2 or H_2S. Brine is consumed by the corrosion reaction.	material (W44)	
	BRAGFLO	Laboratory-scale experimental measurements of gas generation rates at expected room temperatures are used to account for the effects of biofilms and chemical reactions.	Effects of biofilms on microbial gas generation ***(W48)*** Effects of temperature on microbial gas generation ***(W45)*** Chemical effects of corrosion ***(W51)***	R
	BRAGFLO	The rate of ~~biodegradation~~ ***microbial gas production*** is dependent on the amount of liquid present. It is assumed that ~~biodegradation~~ ***microbial activity*** neither produces nor consumes water. ~~Gas generation by microbial degradation~~ ***Significant microbial activity*** ~~takes place~~***occurs*** in half the simulations. In half of the simulations with microbial ~~gas generation~~***activity***, microbes consume all of the cellulosics but none of the plastics and rubbers. In the other half of the simulations with microbial ~~gas generation~~***activity***, microbes consume all of the cellulosics and all of the plastics and rubbers. Microbial ~~gas generation~~***production*** will continue until all biodegradable ~~organic materials~~***CPR materials*** are consumed if brine is present. The MgO backfill will react with ***all of the*** CO_2 and remove it from the gas***eous*** phase.	Brine inflow ***(W40)*** ~~Degradation~~ ***Consumption*** of ***CPR*** ~~organic material~~ ***(W44)*** Waste inventory ***(W2)***	R
	BRAGFLO	Gas dissolution in brine is of negligible consequence.	Fluid flow caused by gas production ***(W42)***	R
	BRAGFLO	The gas***eous*** phase is assigned the properties of hydrogen (general assumption 8).	Fluid flow caused by gas production ***(W42)***	See above
6.4.3.4 Chemical Conditions in the Repository SOTERM-2***.0*** Conceptual Framework of Chemical Conditions				
	NUTS PANEL	Chemical conditions in the repository will be constant. Chemical equilibrium is assumed for all reactions that occur between brine in the repository, waste, and abundant minerals, with the exceptions of gas generation and redox reactions.	Speciation ***(W56)*** Redox kinetics ***(W66)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~***CRA*** Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
		NUTS PANEL	Brine and waste in the repository will contain a uniform mixture of dissolved and solid-state species. ***All actinides have instant access to all repository brine.*** ~~No microenvironments that influence the overall chemical environment will persist.~~	Heterogeneity of waste forms ***(W3)*** Speciation ***(W56)***	C
		NUTS PANEL	***No microenvironments that influence the overall chemical environment will persist.***	***Speciation (W56)***	***R***
		NUTS PANEL	For the undisturbed performance and E2 scenarios, brine in the waste panels has the composition of Salado brine. For E1 and E1E2 scenarios, all brine in the waste panel intersected by the borehole has the composition of Castile brine.	Speciation ***(W56)***	R
		NUTS PANEL	Chemical conditions in the waste panels will be reducing. However, a condition of redox disequilibrium will exist between the possible oxidation states of the actinide elements.	Redox kinetics ***(W56)*** Speciation ***(W56)*** Effects of metal corrosion ***(W64)***	R
		NUTS PANEL	The ~~pmH~~***pH*** and ~~pCO_2~~***f_{CO2}*** in the waste panels will be controlled by the equilibrium between brucite and ~~magnesite~~***hydromagnesite ($Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$)*** (A result of this assumption is low ~~pCO_2~~ ***f_{CO2}*** and ~~alkaline~~***mildly basic*** conditions).	Speciation ***(W56)*** Backfill chemical composition ***(W10)***	R
6.4.3.5 Dissolved Actinide Source Term SOTERM-3.3 The FMT Computer Code					
		NUTS PANEL	Radionuclide dissolution to solubility limits is instantaneous.	Dissolution of waste ***(W58)***	C
		NUTS PANEL	Six actinides (Th, U, Np, Pu, ~~Cm~~***Am***, and ~~Am~~***Cm***) are considered in PANEL for calculations of radionuclide transport of brine (up a borehole). ***Four actinides (Th, U, Pu, and Am) are considered in NUTS for calculations of radionuclide transport in brine (porous materials) (Leigh 2003).*** Choice of radionuclides is discussed in Appendix ***TRU WASTE, Table TRU WASTE-9***~~WCA~~.	Waste inventory ***(W2)***	R
		NUTS	The reducing conditions in the	Speciation ***(W56)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~***CRA*** Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
		PANEL	repository will eliminate significant concentrations of ~~Am(V), Pu(V), Pu(VI), and NP(VI)~~***Np(VI), Pu(V), Pu(VI), and Am(V)***species. Am and Cm will exist predominantly in the +III oxidation state, Th in the +IV oxidation state. It is assumed that the solubilities and K_ds of ~~Pu, Np, and U~~***U, Np, and Pu*** will be dominated by one of the remaining oxidation states: ~~Pu(III) or Pu(IV), Np(IV) or NP(V), U(IV) or U(VI)~~***U(IV) or U(VI), Np(IV or Np(V), and Pu(III) or Pu(IV).***	Redox kinetics ***(W66)***	
		NUTS PANEL	For a given oxidation state, the different actinides exhibit similar chemical behavior and thus have similar solubilities.	Speciation ***(W56)***	R
		~~NUTS PANEL~~	~~Organic ligands will not significantly affect solubility.~~	~~Waste inventory~~ ~~Dissolution of waste~~ ~~Organic ligands~~ ~~Organic complexation~~	~~R~~
		NUTS PANEL	For undisturbed performance and for all aspects of disturbed performance except for cuttings and cavings releases, radionuclide-bearing compounds are distributed evenly throughout the disposal panel.	Waste inventory ***(W2)*** Heterogeneity of waste forms ***(W3)***	R
		NUTS PANEL	Mobilization of actinides in the gas phase is negligible.	Dissolution of waste ***(W58)***	R
		NUTS PANEL	Actinide concentrations in the repository will be inventory limited when the mass of an actinide becomes depleted such that the predicted solubilities cannot be achieved.	Dissolution of waste ***(W58)***	R
6.4.3.6 Source Term for Colloidal Actinides					
		NUTS PANEL	Four types of colloids ~~comprise~~***constitute*** the source term for colloidal actinides; microbes, humic substances, intrinsic colloids, and mineral fragments.	Colloid formation and stability ***(W79)*** Humic and fulvic acids ***(W70)***	R
		NUTS PANEL	The only intrinsic colloids that will form are those of the plutonium Pu(IV) polymer.	Colloid formation and stability ***(W79)***	R
		NUTS PANEL	Concentrations of intrinsic colloids and mineral-fragment colloids are modeled as constants that were based	Colloid formation and stability ***(W79)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
			on experimental observations. Humic and microb~~e~~***ial*** colloid***al*** actinide concentrations are modeled as proportional to dissolved actinide concentrations.		
		NUTS PANEL	The maximum concentration of each actinide associated with each colloid type is constant.	Actinide sorption ***(W61***)	R
6.4.4 Shafts and Shaft Seals MASS-12***.0*** Shafts and Shaft Seals					
		BRAGFLO	General Assumptions 1 to 8.		See above
		BRAGFLO	The four shafts connecting the repository to the surface are represented by a single shaft with a cross-section and volume equal to the total volume of the four real shafts and separated from the waste by ***less than*** the distance of the nearest real shaft.	Disposal geometry ***(W1)***	R
		BRAGFLO	The seal system is represented ***by an upper and lower shaft region representing a composite of the actual materials in those regions***. ~~nine materials occupying eleven model regions.~~	Seal geometry ***(W6)*** Seal physical properties ***(W7)***	R
		BRAGFLO	The shaft is surrounded by a DRZ which heals with time. The DRZ is represented through the ***composite*** permeabilities of the shaft system itself, rather than as a discrete zone. The effective permeability of shaft ~~salt, clay and concrete seals~~***materials*** are adjusted ***at 200 years***~~several times~~ after closure to reflect consolidation and possible degradation. Permeabilities are constant for ~~asphalt and earthen fill components.~~***the shaft seal materials through the Rustler formation.***	Salt creep ***(W20)*** Consolidation of seals (W36) ~~Disturbed rock zone~~ ***DRZ (W18)*** Microbial growth on concrete ***(W76)*** Chemical degradation of seals ***(W74)*** Mechanical degradation of seals ***(W37)***	R
		BRAGFLO	Concrete shaft components ***of the lower shaft*** are modeled as if they degrade ~~400 years~~ after emplacement.	Mechanical degradation of seals	C
		NUTS	Radionuclides are not retarded by the seals.	Actinide sorption ***(W61)*** Speciation ***(W56)***	C
6.4.5 The Salado MASS-13***.0*** Salado					

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
		BRAGFLO	General Assumptions 1 to 8.		See above
6.4.5.1 Impure Halite MASS-13.1 High Threshold Pressure for Halite-Rich Salado Rock Units					
		BRAGFLO	Rock and hydrologic properties are constant.	Stratigraphy ***(N1)***	R
6.4.5.2 Salado Interbeds MASS-13.3 The ~~Anhydrite Interbed~~ Fracture Model					
		BRAGFLO	Interbeds have a fracture-initiation pressure above which local fracturing and changes in porosity and permeability occur in response to changes in pore pressure. A power function relates the permeability increase to the porosity increase. A pressure is specified above which porosity and permeability do not change.	Disruption caused by gas effects ***(W25)***	R
		BRAGFLO	Interbeds have identical physical properties; they differ only in position, thickness, and some fracture parameters.	Saturated groundwater flow ***(N23)***	R
6.4.5.3 Disturbed Rock Zone MASS-13.4 Flow in the Disturbed Rock Zone					
		BRAGFLO	The permeability of the DRZ is ~~constant and higher than intact Salado~~ ***sampled with the low value similar to intact halite and a high value representing a fractured material.*** The DRZ porosity is equal to the porosity of impure halite to plus 0.29 percent.	Disturbed rock zone ***(W18)*** Roof falls ***(W22)*** Gas explosions ***(W27)*** Seismic activity ***(N12)*** Underground boreholes ***(W39)***	C-R
6.4.5.4 Actinide Transport in the Salado MASS-13.5 Actinide Transport in the Salado					
		NUTS	Dissolved actinides and colloidal actinides are transported by advection in the Salado. Diffusion and dispersion are assumed negligible.	Advection ***(W90)*** Diffusion ***(W91)*** Matrix diffusion ***(W92)***	R
		NUTS	Sorption of actinides in the anhydrite interbeds, colloid retardation, colloid transport at higher than average velocities, co-precipitation of minerals containing actinides, channeled flow, and viscous fingering are not modeled.	Actinide sorption ***(W61)*** Colloid transport ***(W78)*** Colloid filtration ***(W80)*** Colloid sorption ***(W81)*** Fluid flow caused by gas production ***(W42)*** Fracture flow ***(N25)***	R
		NUTS	Radionuclides having ***the same elemental form***~~similar half lives~~ are	Radioactive decay and ingrowth ***(W12)***	R

Table MASS-1. General Modeling Assumptions *—* ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
			grouped as discussed in Appendix ***TRU WASTE*** ~~WCA~~.	ingrowth ***(W12)***	
		NUTS	Sorption of actinides in the borehole is not modeled.	Actinide sorption ***(W61)***	C
6.4.6 Units Above the Salado MASS-14*.0* Geologic Units above the Salado					
		SECOTP2D	Above the Salado, lateral actinide transport to the accessible environment can occur only through the Culebra.	Saturated groundwater flow ***(N23)*** Unsaturated groundwater flow ***(N24)*** Solute transport ***(W77)***	R
6.4.6.1 ~~Unnamed Lower Member~~***Los Medaños***					
		~~SECOFL2D~~ ***MODFLOW-2000*** BRAGFLO	The ~~unnamed lower member~~ ***Los Medaños*** member of the Rustler Formation, Tamarisk, and Forty-niner are assumed to be impermeable.	Saturated groundwater flow (N23)	C
6.4.6.2 The Culebra MASS-15*.0* Culebra ~~Appendix~~ *Attachment* TFIELD					
		~~SECOFL2D~~ ***MODFLOW-2000*** SECOTP2D	General Assumptions 1, 6, and 8 ***(see first page of this table).***		See above
		~~SECOFL2D~~ ***MODFLOW-2000*** SECOTP2D	For fluid flow the Culebra is modeled as a uniform (single-porosity) porous medium. For radionuclide transport a double-porosity model is used (advection in high permeability features and diffusion and sorption in low-permeability features).	Saturated groundwater flow ***(N23)*** Fracture flow ***(N25)*** Advection ***(W90)*** Diffusion ***(W91)***	R
		~~SECOFL2D~~ ***MODFLOW-2000***	The Culebra flow field is determined from the observed hydraulic conditions and estimates of the effects of climate change and potash mining outside the controlled area, and does not change with time unless mining is predicted to occur in the disposal system in the future.	Saturated groundwater flow ***(N23)*** Climate change ***(N61)*** Precipitation (for example, rainfall) ***(N59)*** Temperature ***(N60)*** Changes in groundwater flow caused by mining ***(H37)***	R
		BRAGFLO	The Culebra is assigned a single permeability to calculate brine flow into the unit from an intrusion borehole.	Natural borehole fluid flow (H31) Waste-induced borehole flow ***(H32)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix	Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
	~~SECOFL2D~~ ***MODFLOW-2000***	Gas flow in the Culebra is not modeled. Gas from the repository does not affect fluid flow in the Culebra.	Saturated groundwater flow ***(N23)*** Fluid flow caused by gas production ***(W42)***	R
	BRAGFLO ~~SECOFL2D~~ ***MODFLOW-2000*** SECOTP2D	Different thicknesse~~s~~ of the Culebra are assumed for BRAGFLO, ~~SECOFL2D~~ ***MODFLOW-2000***, and SECOTP2D calculations, although the transmissivities are consistent.	Effects of preferential pathways ***(N27)***	R
	~~GRASP-INV~~ ***PEST***	Uncertainty in the spatial variability of the Culebra transmissivity is accounted for by statistically generating many ~~transmissivity~~ ***T***-fields.	Saturated groundwater flow ***(N23)*** Fracture flow ***(N25)*** Shallow dissolution ***(N16)***	R
	~~SECOFL2D~~ ***MODFLOW-2000*** BRAGFLO	Potentiometric heads are set on the edges of the regional grid to represent flow in a portion of a much larger hydrologic system.	Groundwater recharge ***(N54)*** Groundwater discharge ***(N53)*** Changes in groundwater recharge and discharge ***(N56)*** Infiltration ***(N55)***	R
6.4.6.2.1 Transport of Dissolved Actinides in the Culebra MASS-15.2 Dissolved Actinide Transport and Retardation in the Culebra				
	SECOTP2D	Dissolved actinides are transported by advection in high-permeability features and diffusion in low permeability features.	Solute transport ***(W77)*** Advection ***(W90)*** Diffusion ***(W91)*** Matrix diffusion ***(W92)***	R
	SECOTP2D	Sorption occurs on dolomite in the matrix. Sorption on clays present in the Culebra is not modeled.	Actinide sorption ***(W61)*** Changes in sorptive surfaces ***(W63)***	C
	SECOTP2D	Sorption is represented using a linear isotherm model.	Actinide sorption ***(W61)*** Kinetics of sorption ***(W62)***	R
	SECOTP2D	The possible effects on sorption of the injection of brines from the Castile and Salado into the Culebra are accounted for in the distribution of actinide K_ds.	Actinide sorption ***(W61)*** Groundwater geochemistry ***(N36, N37)*** Natural borehole fluid flow ***(H31)***	R
	SECOTP2D	Hydraulically-significant fractures are assumed to be present everywhere in the Culebra.	Advection ***(W90)***	C
6.4.6.2.2 Transport of Colloidal Actinides in the Culebra MASS-15.3 Colloidal Actinide Transport and Retardation in the Culebra				

Table MASS-1. General Modeling Assumptions — (Continued)

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
		SECOTP2D	Humic actinides are chemically retarded identically to dissolved actinides and are treated as dissolved actinides.	Advection ***(W90)*** Diffusion ***(W91)*** Colloid transport ***(W78)*** Microbial transport ***(W87)***	R
		SECOTP2D	The concentration of intrinsic colloids is sufficiently low to justify elimination from ~~performance assessment~~*PA* transport calculations.		R
		SECOTP2D	Microbial colloids and mineral fragments are too large to undergo matrix diffusion. Filtration of these colloids occurs in high permeability features (which is modeled using a decay approach). Attenuation is so effective that associated actinides are assumed to be retained within the disposal system and are not transported in SECOTP2D.	Microbial transport ***(W87)*** Colloid sorption ***(W81)***	R
6.4.6.2.3 Subsidence Due to Potash Mining MASS-15.4 Subsidence Caused by Potash Mining in the Culebra					
		~~SECOFL2D~~ ***MODFLOW-2000***	The effect of potash mining is to increase the hydraulic conductivity in the Culebra by a factor from 1 to 1,000.	Potash mining ***(H13)*** Changes in groundwater flow caused by mining ***(H37)***	Reg.
6.4.6.3 The Tamarisk					
		~~SECOFL2D~~ ***MODFLOW-2000*** BRAGFLO	The Tamarisk is assumed to be impermeable.	Saturated groundwater flow ***(N23)***	R
6.4.6.4 The Magenta					
		BRAGFLO	General Assumptions 1 to 8 ***(see first page of this table).***		See above
		BRAGFLO	The Magenta permeability is set to the lowest value measured near to the center of the WIPP site. This increases the flow into the Culebra.	Saturated groundwater flow ***(N23)***	R
		NUTS	No radionuclides entering the Magenta will reach the accessible environment. However, the volumes of brine and actinides entering and stored in the Magenta are modeled.	Solute transport ***(W77)***	R
6.4.6.5 The Forty-niner					
		BRAGFLO	The Forty-niner is assumed to be impermeable.	Saturated groundwater flow ***(N23)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~***CRA*** Section and Appendix	Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
6.4.6.6 Dewey Lake				
	BRAGFLO	General Assumptions 1 to 8 ***(see first page of this table).***		See above
	NUTS	The sorptive capacity of the Dewey Lake is sufficiently large to prevent any release over 10,000 years.	Saturated groundwater flow ***(N23)*** Actinide sorption ***(W61)***	R
6.4.6.7 Supra-Dewey Lake Units				
	BRAGFLO	General Assumptions 1 to 8 ***(see first page of this table).***		See above
	BRAGFLO	The units above the Dewey Lake are a single hydrostratigraphic unit.	Stratigraphy ***(N1)***	R
	BRAGFLO	The units are thin and predominantly unsaturated.	Unsaturated groundwater flow (N24) Saturated groundwater flow ***(N23)***	R
6.4.7 The Intrusion Borehole MASS-16***.0*** Intrusion Borehole				
6.4.7.1 Releases During Drilling				
	CUTTINGS_S BRAGFLO- ~~DBR~~ ***DRSPALL***	Any actinides that enter the borehole are assumed to reach the surface.	—	C
MASS-16.1 Cuttings, Cavings, and Spall Releases during Drilling				
	BRAGFLO PANEL CUTTINGS_S ***DRSPALL***	Future drilling practices will be the same as they are at present.	Oil and gas exploration ***(H1)*** Potash exploration ***(H2)*** Oil and gas exploitation ***(H4)*** Other resources ***(H8)*** Enhanced oil and gas recovery ***(H9)***	Reg.
	CUTTINGS_S DRSPALL	Releases of particulate waste material are modeled (cuttings, cavings, and spallings). Releases are corrected for radioactive decay until the time of intrusion.	Drilling fluid flow ***(H21)*** Suspension of particles ***(W82)*** Cuttings ***(W84)*** Cavings ***(W85)*** Spallings ***(W86)***	R
	CUTTINGS_S	***Degraded waste properties are***~~Particle waste shear is~~ based on properties of marine clays, considered a worst case	Cavings ***(W85)***	C
	DRSPALL	***A hemispherical geometry with one-dimensional spherical symmetry defines the flow field and cavity in the waste***	***Spallings (W86)***	***C***

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
		DRSPALL	***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***	***Spallings (W86)***	***C***
		DRSPALL	***Shape factor is 0.1, corresponding to particles that are easier to fluidize and entrain in the flow***	***Spallings (W86)***	***C***
6.4.7.1.1 Direct Brine Release During Drilling MASS-16.2 Direct Brine Releases during Drilling					
		BRAGFLO PANEL	Brine containing actinides may flow to the surface during drilling. Direct brine release will have negligible effect on the ***long-term*** pressure and saturation in the waste panel.	Blowouts ***(W23)***	R
		BRAGFLO	A two-dimensional grid (one degree dip) on the scale of the waste disposal region is used for direct brine release calculations.	Blowouts ***(H23)***	R
		BRAGFLO ***CCDFGF***	Calculation of direct brine release from several different locations provides reference results for the variation in release associated with location.	Blowouts ***(H23)***	R
6.4.7.2 Long-Term Releases Following Drilling MASS-16.3 Long-Term Properties of the Abandoned Intrusion Borehole					
		BRAGFLO ***CCDFGF***	Plugging and abandonment of future boreholes are assumed to be consistent with practices in the Delaware Basin.	Natural borehole fluid flow ***(H31)*** Waste-induced borehole flow ***(H32)***	Reg.
6.4.7.2.1 Continuous Concrete Plug through the Salado and Castile					
		BRAGFLO ***CCDFGF***	A continuous concrete plug is assumed to exist throughout the Salado and Castile. Long-term releases through a continuous plug are analogous to releases through a sealed shaft.	Natural borehole fluid flow ***(H31)*** Waste-induced borehole flow ***(H32)***	Reg-R
6.4.7.2.2 The Two-Plug Configuration					
		BRAGFLO	A lower plug is located between the Castile brine reservoir and underlying formations. A second plug is located immediately above the Salado. The brine reservoir and waste panel are in direct communication though an open	Natural borehole fluid flow ***(H31)*** Waste-induced borehole flow ***(H32)***	Reg.-R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
			cased hole.		
		BRAGFLO	The casing and upper concrete plug are assumed to fail after 200 years, and the borehole is assumed to be filled with silty-sand like material. At 1,200 years after abandonment the permeability of the borehole below the waste panel is decreased by one order of magnitude as a result of salt creep.	Natural borehole fluid flow ***(H31)*** Waste-induced borehole flow ***(H32)***	R
6.4.7.2.3 The Three-Plug Configuration					
		BRAGFLO	In addition to the two plug configuration, a third plug is placed within the Castile above the brine reservoir. ***The third plug is assumed not to fail over the regulatory time period***.~~This third plug behaves in a similar manner to the lower plug in the two-plug configuration.~~	Natural borehole fluid flow ***(H31)*** Waste-induced borehole flow ***(H32)***	Reg.-R
6.4.8 Castile Brine Reservoir MASS-18.***0*** Castile Brine Reservoir					
		BRAGFLO	The Castile region is assigned a low permeability, which ~~prevents~~ ***inhibits*** fluid flow. Brine occurrences in the Castile are bounded systems. Brine reservoirs under the waste panels are assumed to have limited extent and interconnectivity, with effective radii on the order of several hundred meters.	Brine reservoirs ***(N2)***	R
6.4.9 Climate Change MASS-17.***0*** Climate Change					
		~~SECOFL2D~~ ***SECOTP2D***	Climate-related factors are treated through recharge. A parameter called the Climate Index is used to scale the Culebra flux field.	Climate change ***(N61)*** Temperature ***(N60)*** Precipitation (for example, rainfall) ***(N59)***	R
6.4.10 Initial and Boundary Conditions for Disposal System Modeling					
6.4.10.1 Disposal System Flow and Transport Modeling (BRAGFLO and NUTS)					
		BRAGFLO	There are no gradients for flow in the far-field of the Salado, and pressures are above hydrostatic, but below lithostatic. Excavation and waste emplacement result in partial drainage of the DRZ.	Saturated groundwater flow ***(N23)*** Brine inflow ***(W40)***	R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~***CRA*** Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
		BRAGFLO	An initial water-table surface is set in the Dewey Lake at an elevation of 3,215 ~~feet~~ ***ft*** (980 m~~eters~~) above mean sea level. The initial pressures in the Salado are extrapolated from a sampled pressure in MB139 at the shaft and are in hydrostatic equilibrium. The excavated region is assigned an initial pressure of one atmosphere. The liquid saturation of the waste-disposal region is consistent with the liquid saturation of emplaced waste. Other excavated regions are assigned zero liquid saturation, except the shaft which is fully saturated.	Saturated groundwater flow ***(N23)***	R
		NUTS	Molecular transport boundary conditions are no diffusion or dispersion in the normal direction across far-field boundaries. Initial actinide concentrations are zero everywhere except in the waste.	Radionuclide decay and ingrowth ***(W12)*** Solute transport ***(W77)***	R
6.4.10.2 Culebra Flow and Transport Modeling (~~SECOFL2D~~***MODFLOW-2000***, SECOTP2D)					
		~~SECOFL2D~~ ***MODFLOW-2000***	Constant head ***and no flow*** boundary conditions are set on the far-field boundaries of the ~~regional~~ flow model~~. Constant head boundary conditions are also set on the boundaries of the local domain, and are derived by interpolating the solution of the regional domain.~~.	Saturated groundwater flow ***(N23)***	R
		~~SECOFL2D~~ ***MODFLOW-2000***	Initial actinide concentrations in the Culebra are zero.	Solute transport ***(W77)***	R
6.4.10.3 Initial and Boundary Conditions for Other Computational Models					
		NUTS PANEL BRAGFLO (direct brine release) CUTTINGS_S	Initial and boundary conditions interpolated from previously executed BRAGFLO calculation.		R
6.4.12 Sequences of Future Events					
		CCDFGF	Each 10,000 year future (random sequence of future events) is generated by randomly and repeatedly sampling: the time between drilling events; the location of drilling events; the activity level of the waste	Oil and gas exploration ***(H1)*** Potash exploration ***(H2)*** Oil and gas exploitation ***(H4)*** Other resources ***(H8)***	Reg.-R

Table MASS-1. General Modeling Assumptions — (Continued)

CCACRA Section and Appendix		Code	Modeling Assumption	Related FEP in Appendix Attachment SCR	Assumption Considered*
			penetrated by each drilling intrusion; the plug configuration of the borehole, and the penetration of a Castile brine reservoir, and by randomly sampling the occurrence of mining in the disposal system.	Enhanced oil and gas recovery ***(H9)*** Natural borehole fluid flow ***(N31)*** Waste-induced borehole flow ***(H32)***	
6.4.12.1 Active and Passive Institutional Controls in Performance Assessment Chapter 7.0					
		CCDFGF	Active institutional controls are effective for 100 years and completely eliminate possibility of incompatible activities. ***No credit is taken for passive institutional controls.*** Passive institutional controls are effective for 600 years and reduce rate of incompatible events to 0.01 of the rate during the following uncontrolled period.		Reg.-R
6.4.12.2 Number and Time of Drilling Intrusions					
		CCDFGF	Drilling may occur after 100 years according to a Poisson process.	Loss of records ***(H57)*** Oil and gas exploration ***(H1)*** Potash exploration ***(H2)*** Oil and gas exploitation ***(H4)*** Other resources ***(H8)***	Reg.-R
6.4.12.3 Location of Intrusion Boreholes					
		CCDFGF	The waste disposal region is discretized with 144 regions with the probability of each region being intersected equal. A borehole can penetrate only one region.	Disposal geometry ***(W1)***	R
6.4.12.4 Activity of the Intersected Waste Appendix WCA ***TRU WASTE***					
		CCDFGF	569 ***693*** waste streams identified for contact-handled (CH)-TRU and all ***86*** the remote-handled (RH)-TRU waste ***streams were***was grouped (binned) together into one equivalent or average (WIPP-scale) RH-TRU waste stream.	Heterogeneity of waste form ***(W3)***	R
6.4.12.5 Diameter of the Intrusion Borehole ***CCA*** Appendix DEL					
		CUTTINGS_S	The diameter of the intrusion borehole is constant at 12.25 in.ches (31.12 centimeters ***cm***).		Reg.-R

Table MASS-1. General Modeling Assumptions — (Continued)

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
6.4.12.6 Probability of Intersecting a Brine Reservoir					
		CCDFGF	One brine reservoir is assumed to exist below the waste panels. The probability that a deep borehole intersects a brine reservoir below the waste panels is ***sampled uniformly from 0.01 to 0.60.*** ~~0.08. Brine reservoirs may be depleted by boreholes drilled in the waste disposal region that do not intersect waste (for example, through intact rock).~~	Brine reservoirs ***(N2)***	R
6.4.12.7 Plug Configuration in the Abandoned Intrusion Borehole					
		CCDFGF	The two-plug configuration has a probability of ~~0.68~~***0.698.*** The three-plug configuration has a probability of ~~0.30~~***0.289***. The continuous concrete plug has a probability of ~~0.02~~***0.015***.		Reg.-R
6.4.12.8 Probability of Mining Occurring in the Land Withdrawal Area					
		CCDFGF	Mining in the disposal system occurs a maximum of once in 10,000 years (a 10^{-4} probability per year).		Reg.-R
6.4.13 Construction of a Single CCDF					
		CCDFGF	Deterministic calculations are executed with BRAGFLO, NUTS, ~~SECOFL2D~~ ***MODFLOW-2000***, SECOTP2D, CUTTINGS_S, and PANEL to generate reference conditions. These reference conditions are used to estimate the consequences associated with random sequences of future events. These are in turn used to develop CCDFs.		R
		CCDFGF	10,000 random sequences of future events are generated for each CCDF plotted.		R
6.4.13.1 Constructing Consequences of the Undisturbed Performance Scenario					
		CCDFGF	A BRAGFLO and NUTS calculation with undisturbed conditions is sufficient for estimating the consequences of the undisturbed performance scenario.		R
6.4.13.2 Scaling Methodology for Disturbed Performance Scenarios					
		CCDFGF	Consequences for random sequences of future events are constructed by scaling the consequences associated		R

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ ***Attachment*** SCR	Assumption Considered*
			with deterministic calculations (reference conditions) to other times, generally by interpolation but sometimes by assuming either similarity or no consequence.		
6.4.13.3 Estimating Long-Term Releases from the E1 Scenario					
		CCDFGF NUTS	Reference conditions are calculated or estimated for intrusions at 100, 350, 1,000, 3,000, 5,000, 7,000, and 9,000 years.	Waste-induced borehole flow ***(H32)***	R
		~~SECOTP2D~~	~~Reference behavior for actinide transport in the Culebra is calculated for intrusions at 350 and 1,000 years.~~	~~Solute transport~~	~~R~~
6.4.13.4 Estimating Long-Term Releases from the E2 Scenario					
		CCDFGF NUTS SECOTP2D	The methodology is similar to the methodology for the E1 scenario. For multiple ***E1*** intrusions ***into the same panel,*** the additional source term to the Culebra for the second and subsequent intrusions is assumed to be negligible.	Waste-induced borehole flow ***(H32)*** Waste inventory ***(W2)***	R
6.4.13.5 Estimating Long-Term Releases from the E1E2 Scenario					
		CCDFGF PANEL	The concentration of actinides in liquid moving up the borehole assumes homogeneous mixing within the panel.	Waste-induced borehole flow ***(H32)***	C
		PANEL	Any actinides that enter the borehole reach the Culebra.	Waste-induced borehole flow ***(H32)***	C
		CCDFGF ***PANEL***	***Reference conditions are calculated or estimated for intrusion at 100, 300, 1,000, 2,000, 4,000, 6,000 and 9,000 years.***	***Oil and Gas Exploration (H1)***	
6.4.13.6 Multiple Scenario Occurrences					
		CCDFGF PANEL	The panels are assumed not to be interconnected for long term brine flow.	Saturated groundwater flow ***(N23)*** Unsaturated groundwater flow ***(N24)***	R
6.4.13.7 Estimating Releases During Drilling for All Scenarios					
		CCDFGF PANEL NUTS	Repository conditions will be dominated by Castile brine if any borehole connects to a brine reservoir.	Brine reservoirs ***(N2)*** Natural borehole fluid flow ***(H31)***	R
		CUTTINGS_S PANEL CCDFGF	Depletion of actinides in parts of the repository that have been penetrated by boreholes is not accounted for in calculating the releases from	Waste-induced borehole flow ***(N32)*** Waste inventory ***(W2)***	C

Table MASS-1. General Modeling Assumptions — ~~(~~Continued~~)~~

~~CCA~~*CRA* Section and Appendix		Code	Modeling Assumption	Related FEP in ~~Appendix~~ *Attachment* SCR	Assumption Considered*
			subsequent intrusions at such locations.		
6.4.13.8 Estimating Releases in the Culebra and the Impact of the Mining Scenario					
		CCDFGF ~~SECOFL2D~~ ***MODFLOW-2000*** SECOTP2D	Releases from intrusions at random times in the future are scaled from releases calculated at 100 years with a unit source of radionuclides in the Culebra.		R
		CCDFGF	Actinides in transit in the Culebra when mining occurs are transported in the flow field used for the undisturbed case. Actinides introduced subsequent to mining are transported in the flow field used for the disturbed case (that is, mined case).		R

* R = Reasonable
C = Conservative
Reg. - Based on regulatory guidance
See above - Refers to assumptions 1 through 8 listed at the beginning of this table.

Three other two-dimensional model geometries are used in performance assessment. For fluid flow and transport modeling in the Culebra, the geometry is a horizontal two-dimensional plane (see Sections 6.4.2 and 6.4.6.2). For modeling brine flow from the intruded panel to the borehole during drilling, the geometry is a two-dimensional, horizontal representation of a waste panel (see Section 6.4.7). For modeling brine flow that might occur between an E-type borehole and other boreholes penetrating the repository, the geometry used is a two-dimensional, horizontal representation of the entire repository (see Section 6.4.*2*~~13.6~~). These geometries are mentioned here but not discussed in detail because they are components of other conceptual models requiring geometric assumptions.

The two-dimensional geometry developed for the Salado is based on the assumption that brine and gas flow will converge upon and diverge from the repository horizon. The impact of this conceptual model and its implementation in a two-dimensional grid has been compared to a model that does not make the assumption of convergent and divergent flow (see Attachment 4-1 for additional information). The conceptual model for the Salado includes the slight and variable dip of beds in the vicinity of the repository, which might affect fluid flow.

Above and below the repository, it is assumed that any flow between the borehole or shaft (see Section 6.4.3) and surrounding materials will converge or diverge. With respect to flow in units overlying the Salado, the only purpose of this conceptual model is to determine the quantity (flux) of fluid leaving or entering the borehole or shaft. Fluid movement through the units above the Salado is treated in a different conceptual model (see Section 6.4.6). Below the repository, the possible presence of a brine reservoir is considered to be important, so a hydrostratigraphic layer representing the Castile and a possible brine reservoir in it is included ***(see CCA Appendix***

MASS, Section MASS.4.2 for the disposal system geometry historical context prior to the CCA).

MASS-4.2 ***Change to Disposal System Geometry Since the CCA*** ~~**Historical Context of the Disposal System Geometry**~~

Changes have been made to the disposal system geometry since the first WIPP certification. The disposal system geometry is specifically represented in BRAGFLO. This section describes the methodology used to create the two-dimensional BRAGFLO computational grid used for the 2004 PA calculations. The CRA-2004 grid is similar to that used for the CCA and PAVT, except for the differences that are described below.

The most important changes with respect to the CRA BRAGFLO grid are the implementation of the Option D panel closures and a simplified shaft seal model. Additional grid refinements have also been implemented to increase numerical accuracy and computational efficiency and to reduce numerical dispersion, but these refinements do not entail any changes to conceptual models. All conceptual model changes were approved by the Salado Flow Peer Review Panel in February 2003 (Caporuscio et al. 2003). For completeness, all changes from the CCA/PAVT grid are described here.

MASS-4.2.1 Baseline Grid Changes

The baseline grid used in the CCA and PAVT had (NX, NY) dimensions of (33, 31). The grid used for the CRA-2004 calculations has dimensions (68, 33). The specific changes that have been implemented in the CRA-2004 grid are listed below and then discussed in more detail in the following sections. Logical grids for the CCA/PAVT and CRA are shown in Figures MASS-3 and MASS-4.

Changes implemented in the CRA-2004 Grid:

1. ***A simplified shaft seal model is implemented,***
2. ***Option D type panel closures are implemented,***
3. ***Segmentation of the waste regions is increased,***
4. ***A grid flaring method is redefined and simplified,***
5. ***X spacing of the grid beyond the repository to the north and south is refined, and***
6. ***Layers above and below MB 139 have been made relatively thin (~1 m thick), and Y-spacing in Salado has been changed.***

MASS-4.2.2 Simplified Shaft Seal Model

A shaft seal model is included in the CRA-2004 grid, but it is implemented in a simpler fashion than was used for the CCA and PAVT. A detailed description of the parameters used to define the simplified model is discussed in AP-094 (James and Stein 2002) and the resulting

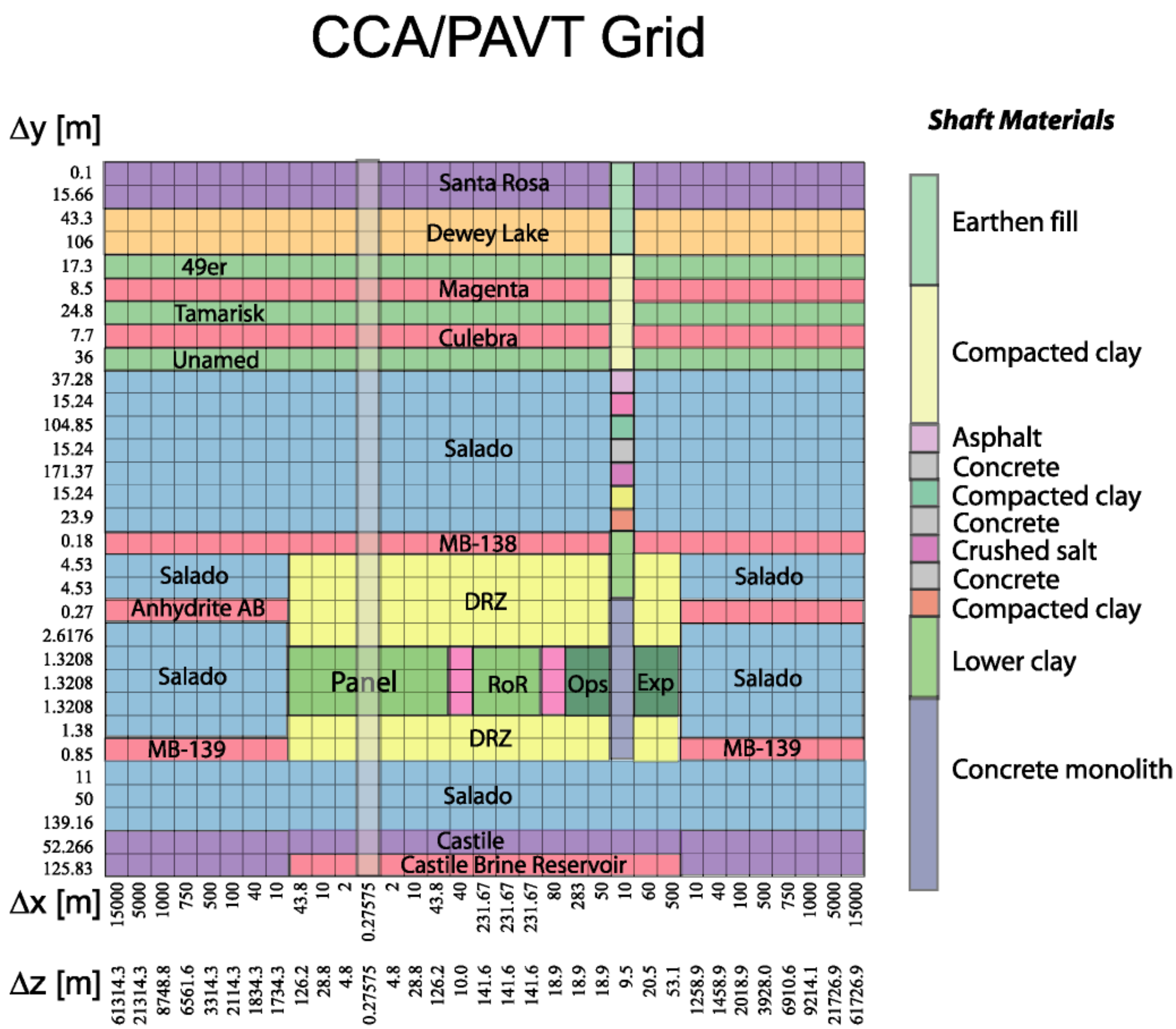

Figure MASS-3. Logical Grid Used for the 1996 WIPP PA BRAGFLO Calculations

analysis report (James and Stein 2003). The model that is used in the 2004 PA is described by Stein and Zelinski (2003a; 2003b), and was approved by the Salado Flow Peer Review panel (Caporuscio et al. 2003).

The new model does not alter the conceptual model of the shaft seal components as described in the CCA. Rather, it represents the behavior of seal components in the repository system model. Specifically, the original 11 separate material layers that defined the shaft model for the CCA were reduced to two layers each with properties equivalent to the composite effect of the original materials combined in series. Additionally, the six time intervals that were used to represent the evolution of the shaft seal materials over time were reduced to two intervals. The CRA and CCA shaft models are graphically compared in Figure MASS-5. The simplified shaft model was tested in the AP-106 calculations (Stein and Zelinski 2003a; 2003b), which supported the Salado Flow Peer Review. The results of this analysis demonstrated that brine flow through the simplified shaft model was comparable to brine flows seen through the