THE WASTE ISOLATION PILOT PLANT PERFORMANCE ASSESSMENT PROGRAM

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) Performance Assessment Program involves a comprehensive analysis of the WIPP project with respect to the recently finalized Environmental Protection Agency regulations regarding the long-term geologic isolation of radioactive wastes. The performance assessment brings together the results of site characterization, underground experimental, and environmental studies into a rigorous determination of the performance of the WIPP as a disposal system for transuranic radioactive waste. The Program consists of scenario development, geochemical, hydrologic, and thermomechanical support analyses and will address the specific containment and individual protection requirements specified in 40 CFR 191 subpart B. Calculated releases from these interrelated analyses will be reported as an overall probability distribution of cumulative release resulting from all processes and events occurring over the 10,000 year post-closure period. In addition, results will include any doses to the public resulting from natural processes occurring over the 1,000 year post-closure period. The overall plan for the WIPP Performance Assessment Program is presented along with approaches to issues specific to the WIPP project.

INTRODUCTION

The fundamental function of a nuclear waste repository is to prevent unacceptable exposures to people or the environment, either now or in the future. Because this requirement extends for many thousands of years, assuring fulfillment of the requirement cannot be demonstrated by operational experience. It can best be appraised by a computer-based simulation using field and laboratory data, combined with the most up-to-date analytical methodologies and expert scientific judgment. The term used to describe all the steps involved in predicting the potential performance of a nuclear waste disposal system, taking into account all engineered and natural components of the system, is "performance assessment."

This paper presents the plans and approaches used in the Waste Isolation Pilot Plant (WIPP) post-closure Performance Assessment Program. The WIPP, located in southeast New Mexico, is a U.S. Department of Energy facility intended to dispose of transuranic (TRU) radioactive wastes generated by defense programs.

The WIPP underground storage facility is located at a depth of 2,150 feet near the middle of a 3,600-foot-thick sequence of relatively pure evaporite strata of Permian age. The evaporite sequence consists primarily of rock salt and anhydrite, and extends from 500 to about 4,100 feet beneath the surface. The formation richest in rock salt, the Salado Formation, is nearly 2,000 feet thick. This formation isolates the storage horizon from any significant hydrological and biological environment. A thickness of at least 1,300 feet of undisturbed evaporite, primarily rock salt, overlies the storage horizon. The salt deposits were formed at least 225 million years ago and have apparently remained isolated from external sources of water since that time.

The following sections describe the specific regulatory criteria applicable to the WIPP project and the approach that will be taken to determine if the post-closure performance of the repository will comply with the regulations.

REGULATORY COMPLIANCE

The primary objective of the WIPP Performance Assessment Program is to determine whether the long-term performance of the facility will comply with the Environmental Protection Agency's regulation on environmental standards for the management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes (40 CFR 191, EPA, 1985). The individual protection and containment requirements of this regulation are applicable to the post-closure performance of the WIPP.

The individual protection requirements described in 40 CFR 191 limit the annual dose received by any member of the public from the disposal system to 25 millirems to the whole body, or 75 millirems to any critical organ. Compliance with these individual protection requirements will be based on an assessment of the performance of the disposal system for a 1000-year period of "undisturbed performance," defined as the predicted behavior of the disposal system given no disruptions by either human intrusion or unlikely natural events. Determining compliance with this requirement entails modeling all potential pathways that are expected to release radionuclides to man in the first 1,000 years post-closure and computing the subsequent dose.

The containment requirements described in 40 CFR 191 define the cumulative release limits of radionuclides to the accessible environment from all credible events and natural processes for 10,000 years after disposal. Activities to be performed to determine compliance with the containment require-

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ments involve modeling the total release from natural processes as well as the release from "relatively likely disruptions" over the 10,000-year period. Specific activities required by the regulations include:

- o Identification of the processes and events that might affect the disposal system (scenario development).
- o Examination of the effects of these processes and events on the performance of the disposal system.
- o Estimation of the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events.

It is further required that the release estimates be incorporated into an overall probability distribution of cumulative release. To accomplish this, a probabilistic analysis for all applicable input parameters, including scenario occurrence, must be performed.

The performance assessment for the WIPP has been initiated and will integrate previous long-term assessments which have been applied to WIPP. The following sections describe the specific activities required to assess the performance of the WIPP repository. The activities are divided into scenario development, hydrology, geochemistry, and support tasks.

SCENARIO DEVELOPMENT

For the purposes of this investigation, the term "scenario" refers to a hypothetical sequence of events whose occurrence might conceivably release radioactive material to the environment during either the 1,000-year or 10,000-year periods specified in 40 CFR 191. To determine the cumulative release of radionuclides to the environment due to all credible mechanisms, the probability of occurrence as well as the release (or consequence) of each specific scenario must be quantified. The total cumulative release (or risk) is then equal to the sum of the products of probability and consequence for all scenarios.

The consequences of a given scenario are dependent upon several factors, including: the nature of the breaching event, the mechanism for moving radionuclides through the breach, the time between disposal and breaching event, the response of the burial medium to the breach, the radionuclide inventory, and the physical and chemical condition of the waste. These factors will be defined for each scenario. Scenario development tasks include:

- o Literature survey;
- o Formulation of credible scenarios;
- o Evaluation of scenario occurrence probabilities;
- o Development of consensus among project participants and review agencies.

Processes and events (including natural processes and events, human activities, and waste and repository effects) that could contribute to release of radioactivity will be identified. Relevant processes and events will be combined into a set of potential scenarios using formal systems techniques (fault and/or event trees). Probability of occurrence of scenarios will be evaluated using a combination of screening calculations, statistical inference from available data, and structured expert opinion techniques.

Scenarios will be divided into two groups: those that result in release due to natural processes, and those that result in release due to inadvertent human intrusion or low probability natural events. Inadvertent human intrusion scenarios currently under consideration include single or dual boreholes connecting the repository with water sources such as a hypothetical brine reservoir, the Culebra Dolomite member of the Rustler Formation (a water-bearing unit above the repository), or the Bell Canyon formation underlying the repository.

HYDROLOGY

The main activities of the hydrology program will be groundwater flow-path modeling and radionuclide transport modeling. The primary task will be to quantify the flow-times that contaminants require to reach the accessible environment along each possible flow-path for each breach scenario, and determine the cumulative volume of contaminated fluid released. An additional area requiring hydrologic input will be the determination of the volumetric flow rate of repository fluid entering the flow-paths for each particular scenario.

Appendix B of 40 CFR 191 acknowledges that the process of modeling groundwater flow and radionuclide transport for 10,000 years contains a considerable amount of uncertainty. This uncertainty should be incorporated within the models. It is therefore necessary to statistically analyze the hydrologic data and construct a stochastic model of flow and transport.

There are two potential flow-paths above the repository (Culebra and Magenta water-bearing units), and one below the repository (Bell Canyon). The hydraulic parameters of these aquifers vary significantly, with the Culebra Dolomite member of the Rustler Formation generally possessing the greatest potential for radionuclide transport. Two of the tasks in the flow-path modeling effort will be to establish which aquifers may significantly contribute to the radionuclide release for a given scenario, and to evaluate if sufficient data exist to model each aquifer.

Rather than apply a full numerical model to each breach scenario, it may be prudent to screen certain scenarios with a simplified, conservative model. Such models may be analytical or semi-numerical but must be based on realistically conservative assumptions. If these screening models indicate that a significant release will result from a given scenario then more sophisticated modeling will be required.

Determination of Flow Regime

The Culebra, as well as other potential flow-paths, consists primarily of fractured dolomite. Whether these aquifers behave as a single or dual porosity medium is a question currently under debate. Analysis of the hydraulic tests currently in progress should resolve this issue. Comparison of modeling results based on different assumptions when applied to the same data will determine underlying assumptions (i.e., single or dual porosity) which best model the data. This approach will be applied to all wells near the site for which hydraulic test data exist. The results will not only be a resolution of the single or dual porosity question, but will also yield the spatial distribution of aquifer parameters (i.e., permeability, storativity).

Flow Modeling

Once the flow regime has been established, a groundwater flow model will be constructed. All the necessary hydrologic and geologic input parameters are obtained from the database. These include static pressure, density, thickness and dip of the aquifer, aquifer parameters, and the hydraulic boundary conditions. The fluid injection rate will be determined for each breach scenario, and is the driving force for radionuclide release.

Because the uncertainty associated with the data must be incorporated in the model, statistical analysis of input parameters is required. Geostatistical techniques such as kreiging will be applied to the appropriate parameters to determine statistical distributions.

Once the input parameters and their associated uncertainties have been collected, flow modeling can proceed. At this point there may be two options available. One method involves an analytical closed-form solution to the stochastically formulated partial differential equation of groundwater flow. It is unclear at this time whether a satisfactory technique exists that includes the effects of multi-dimensions and spatially variable density.

The other option involves the use of a deterministic numerical code in conjunction with a conditional simulation technique. To be applicable to the WIPP site, the flow code must be multi-dimensioned, capable of treating either single or dual porosity media, written in terms of permeability, density, and fluid pressure, and it must account for the effects of dipping beds. The codes that are currently under consideration are SWENT and SWIFT II. To incorporate uncertainty, the deterministic model will be conditioned by the probability distributions of the input parameters. Simulations utilizing either Monte Carlo or Latin Hypercube techniques will be performed.

The output from the stochastic flow model will be the spatial velocity distribution in multi-dimensions along with the probability distribution associated with the velocity at every point in space and time. Once a stochastic flow model is constructed, the hydraulic effects of any given breach scenario can be superimposed on the model and the resulting flow velocity distribution determined.

Radionuclide Transport Modeling

The transient flow velocity distribution and its associated uncertainty is obtained from flow-path modeling. Each breach scenario will have associated with it a mass injection rate of radionuclides into the flow system. This injection rate will be determined through the combined efforts of the hydrology and geochemistry programs.

As with flow-path modeling, there are again options of utilizing: (1) an analytical stochastic approach; or (2) a deterministic numerical model coupled with conditional simulation to model radionuclide transport. A one-dimensional analytical solution to a stochastically formulated advective-dispersion equation does exist. Whether or not this one-dimensional approach is applicable to WIPP will depend on the results of the flow-path modeling.

The other option is to continue with the deterministic numerical model (SWENT or SWIFT II) and utilize its transport capabilities. The transport model can be conditioned on the probability distributions of flow velocities, distribution coefficients, and the mass injection rate of contaminated fluid.

The result from either of these modeling approaches will be a probability distribution of radionuclide release at each boundary point in the model (i.e., the accessible environment) at each time step up to 10,000 years. This modeling effort will be duplicated for each significant breach scenario. When the probability distribution of radionuclide release is summed over space, time, and breach scenario, compliance with 40 CFR 191 can be determined.

Source Water Modeling

Another area of the performance assessment calculations requiring hydrologic input involves source water modeling. This includes both determining the volumetric flow rate of fluid entering the repository for each given scenario, and the volumetric injection rate of contaminated fluid into the flow-paths. This task will be an integrated effort between the hydrology, geochemistry, and supporting analysis groups as described in more detail below.

GEOCHEMISTRY

The most credible mechanism for the migration of radionuclides from a repository to the environment is solution transport in groundwater. Interactions between the waste, groundwater, barrier materials and host rock, controlled by geochemical reactions and reaction kinetics, will determine the composition of this transported solution. These geochemical reactions are controlled by temperature, pressure, and compositional parameters which vary over space and time. To understand and eventually model this behavior, geochemical investigations must focus on three general areas:

- Characterizing and modeling potential sources of groundwater which may come in contact with the waste,
- Characterizing and modeling the repository environmental conditions and determining the amount of radionuclides that can dissolve in a given volume of groundwater under these conditions (source term), and
- Modeling radionuclide precipitation and/or sorption reactions which may occur along potential flow-paths from the repository to the environment.

These geochemical modeling tasks will be performed using the EQ3NR/EQ6 speciation/solubility/reaction path code.[1] Activities that require the modeling of high ionic strength solutions (brine) will use the Pitzer approach[2] which has recently been incorporated as an option in the EQ3NR/EQ6 code.[3] The dependence of the modeling results on the uncertainties in input parameters will be determined using sensitivity analysis techniques. The following sections describe these modeling activities in detail.

Chemical Characteristics of Potential Sources of Water

All potential sources of water which may come in contact with the waste must be physically and chemically characterized. The four potential sources of water which have been recognized are:

- o Salado Formation,
- o Brine Reservoir,
- o Groundwater migration down the repository shaft/seal/disturbed rock zone system, and
- o Bell Canyon.

The amount of radionuclides which can be transported in solution by a given volume of fluid is dependent upon the fluid composition, pressure, and temperature. Important compositional parameters which govern radionuclide solubilities include pH, redox state, and concentration of complexing ligands. All four potential sources of water must be chemically modeled at their place of origin.

Once this geochemical modeling has been completed, the fluids will then be conceptually transported from their place of origin to the repository. While in transit, these fluid compositions will be subject to alteration due to changes in the pressure, temperature, and mineralogy along the flow-path. As a result of these changes, it will be the altered water, rather than the initial water, which will interact with the waste. Therefore, modeling the chemical changes which will occur along the flow-path from the water source to the repository is required. The next four subsections discuss the four potential sources of groundwater.

Migration of Formation Water to Repository: As used here, the term formation water represents three different fluid sources. These are:

- o Intergranular fluid
- o Crystallization fluid
- o Fluid inclusions.

Each of these sources can be distinguished by different fluid chemistries, mechanisms of migration, and volume percentages in the Salado host rock.

The specific tasks included in the geochemical modeling are:

- o Determining the mechanisms for formation fluid migration,
- o Calculating the total volume of mobile fluid,
- o Determining the chemical composition of the three different types of formation fluid,
- o Calculating the thermodynamic state of the fluid (e.g., pH, Eh, speciation, etc.).

There are two dominant mechanisms for the migration of formation fluid. The first and best recognized mechanism is that of fluid inclusion migration up a thermal gradient. If a temperature gradient exists across a brine inclusion, salt will dissolve at the hot surface and precipitate at the cool surface, thus displacing the inclusion toward the heat source. There is, however, a critical gas liquid volume ratio that, if exceeded, will result in the gas-liquid inclusions migrating down the temperature gradient.[4]

The second mechanism is the migration of formation fluids through localized fractures and laterally persistent clay seams. The impetus for this fluid migration is thought to be pressure gradients created by the mining of the repository.

The total volume of formation fluid transportable to the repository will be determined using the volume percent of the formation represented by each of the three fluid types.[5] The volume of rock salt considered in the calculation will include the salt backfill, the disturbed rock zone surrounding the repository, and some conservative volume extending beyond the disturbed rock zone. The value calculated will be the total volume available for transport to the repository and, as such, will err on the side of conservatism.

Brine Reservoir: Interconnection of the repository with a hypothetical brine reservoir located below the repository by a borehole is a scenario that is under consideration. It will therefore be necessary to characterize the geochemical environment which may exist within such a hypothetical brine reservoir. Many brine reservoirs have been identified within Permian basins in the southwestern United States. Two such brine reservoirs, located in the Castile Formation, have been found north of the WIPP site. These two occurrences of pressurized brine have been extensively studied by Popielak, et al., (1983).[6] Specific activities included in this task include determination of: an average brine reservoir composition, redox state, pH, and degree of mineral saturation.

Migration of Water Down the Shaft: Groundwater migration down the shaft/seal system to the repository is a scenario currently being investigated. If these investigations suggest that groundwater may reach the repository via the shaft/seal system during a 10,000-year period, then geochemical modeling of the evolution of the groundwater composition as it migrates toward the repository will be necessary. Reaction path calculations will be used to model irreversible processes of dissolution and precipitation as the water slowly migrates through differing chemical environments.

Bell Canyon: The Bell Canyon Formation is a water-bearing formation which underlies the WIPP site. If it is determined that the distribution of fluid pressure in the Bell Canyon Formation is such that a borehole connection with the repository will result in water rising to the repository, then the composition of this water reaching the repository will have to be determined using the geochemical modeling techniques previously described.

Radionuclide Source Terms

A solubility approach will be taken to determine the maximum amount of radionuclide that can dissolve in water contacting the waste. The solubility approach involves either a theoretical or an experimental determination of the effective solubilities of radionuclides in the repository environment.

Effective solubilities may be quite different than true "thermodynamic" solubilities since only metastable, as opposed to stable equilibrium between the waste and groundwater, will probably be achieved at anticipated repository temperatures. Water which comes in contact with the waste is assumed to become instantly saturated in each radionuclide as determined by its effective solubility. This concentration term is then coupled to diffusive and/or advective transport terms to yield a flux to potential pathways.

Several options exist for determining radionuclide solubilities in a brine environment. Options currently under consideration include: 1) a theoretical approach; 2) natural analogs; and 3) an experimental approach.

Theoretical Approach: Thermodynamic calculations which determine solubilities must be written in terms of "activities" (which can be thought of as "effective" concentrations) rather than actual concentrations. To convert activities to concentrations, an "activity coefficient" term, which is defined as the ratio of activity to concentration, is required. Several theoretical models exist to calculate activity coefficients; however, most of these models, which are based on the Debye-Huckel theory,[7] are applicable only to dilute solutions and will yield large errors if applied to concentrated brines. Two recent models, the hydration theory[8] and the specific ion interaction theory,[2,9] based on semi-empirical extensions to the Debye-Huckel theory, allow the calculations of activity coefficients in concentrated brines. At this time, application of these models to radionuclide solubilities are limited by the current lack of data for the actinide elements. Support for basic research to experimentally determine the behavior of actinides in concentrated solutions would be a major contribution toward accurately assessing the performance of a nuclear waste repository in a salt environment.

Natural Analogs: Natural analog investigations can be performed on a wide variety of sites which provide qualitative data on radionuclide source-terms in a generic salt environment. Although this type of data lacks the accuracy and site specificity required for rigorous performance assessment analysis, it does serve several functions:

- o A first approximation for use in initial calculations,
- o An independent verification of other techniques, and
- o Insight into dissolution and transportation processes.

The advantage of studying natural analogs is that they represent "natural experiments" performed over long periods of time. Examples of natural analog investigations useful to the WIPP project are: an investigation recently published by Langmuir and Melchior (1985) on the geochemistry of Sr and Ra sulfates in some deep brines from the Palo Duro Basin, Texas,[10] and a similar study on the behavior of naturally occurring U and Th in brine aquifers in the Palo Duro Basin by Laul et al. (1985).[11]

Experimental Approach: There is a wealth of existing experimental data on high-level waste/brine interactions, which were obtained in support of the Office of Nuclear Waste Isolation (ONWI) project to determine the suitability of salt deposits as a host for a high-level nuclear waste repository. Most of the experiments were designed to determine the dissolution rates of various waste forms, including spent fuel, commercial reprocessing waste (borosilicate glass), and defense high-level waste in a brine environment. The majority of these experiments were conducted for short periods of time (14 to 28 days). Unfortunately, the duration was too short to reach the degree of saturation necessary to obtain radionuclide solubility data. However, a few experiments have been performed with durations sufficient to reach steady-state concentration of radionuclides of interest to the WIPP project. Once steady-state with respect to a given component is achieved, the observed concentration of that component in solution can be related to the solubility of that component. Additional organizations which are performing experiments on waste-brine interactions include Whiteshell Nuclear Research Establishment (Canada) and the Hahn-Meitner Institute (Federal Republic of West Germany).

Any experimental data on the interactions between brine and nuclear waste would be of value to the WIPP Performance Assessment Program. However, application of this type of experimental data to the WIPP project is limited by the fact that the experimental conditions and materials used in these experiments (such as waste forms, brine, and host rock) are not identical to the conditions and materials specific to the WIPP. If enough experimental data exists over a range of conditions and compositions, however, it may be possible to employ extrapolation techniques to increase the applicability of the data to the WIPP project. Although the data was not obtained under site-specific conditions, it will still serve as a useful verification of solubility data obtained using other techniques.

The previous discussions on options for determining radionuclide source terms have focused on using theoretical modeling techniques or utilizing experimental data obtained from systems similar, but not identical, to the actual system of interest. An alternative technique is to perform experiments using actual waste, barrier materials, host rock, and groundwater appropriate to the WIPP site. These materials would be combined in various combinations and permutations and reacted together at anticipated repository temperatures and pressures. The duration of the experiments would be long enough to allow the system to reach a steady-state condition (i.e., fluid composition is invariant with respect to time). Advantages to this approach are:

- o Data is obtained using actual waste, rock, and groundwater. Uncertainties caused by extrapolation from ideal to real situations are avoided.
- o Problems encountered in the theoretical modeling of concentrated brine solutions are avoided.
- o Detailed data on the formation of radionuclide complexes in a brine environment are not necessary.

- o Any radiolysis effects will be automatically accounted for.
- o Experimental results will yield radionuclide source terms which can be input directly into transport models.

Modeling Geochemical Reactions Along Potential Flow-Paths to the Environment

Modeling the geochemical reactions that may occur between dissolved radionuclides, groundwater, and minerals along potential flow-paths is essential to determine the cumulative release of radionuclides to the environment. This activity will be performed in concert with the hydrologic modeling activities concerned with fluid transport processes along potential flow-paths. Geochemical processes that will be considered include sorption and precipitation.

Adsorption of radionuclides on mineral surfaces can play an important role in retarding the transport of radionuclides through an aquifer. Thus, adsorption/desorption processes can create a differential between the radionuclide velocity and the groundwater velocity along the flow-path. Since a longer time is spent in transit, this process can result in lowering the cumulative release of radionuclides which have half-lives that are equal to or less than the groundwater travel times to the accessible environment.

Modeling techniques used to consider sorption processes will be incorporated in the hydrologic flow model. Hydrologic transport codes currently under consideration for use include SWENT and SWIFT II, both of which have the capability to consider adsorption/desorption along the flow-path.

Precipitation of radionuclide-bearing phases along the flow-path can result in the permanent immobilization of radionuclides. The solubility of a radionuclide is a function of several factors, including temperature, pressure, redox state, pH, and the concentration of complexing ligands. If the solubility of a given radionuclide in the repository environment is higher than the solubility along some region of the flow-path, then precipitation of some radionuclide-bearing mineral along the flow-path would be expected (assuming rapid precipitation kinetics). Thus, the cumulative release of radionuclides to the accessible environment is a function not only of the solubilities in the repository environment, but also along the entire flow-path. Precipitation processes along the flow-path will be modeled using the speciation/solubility/reaction path code EQ3NR/EQ6.

Supporting Analysis

Supporting analysis includes a variety of thermomechanical modeling activities which support the scenario development, hydrology, and geochemistry tasks. Examples of support modeling activities include modeling the temperature and pressure gradient surrounding the repository as a function of time, and determining the repository residual porosity as a function of time.

SUMMARY

The primary objective of the WIPP Performance Assessment Program is to determine whether the long-term performance of the facility will comply with U.S. Environmental Protection Agency Rule 40 CFR 191.[12]

Specific activities required by the regulations include:

- o Identifying processes and events that might affect the disposal system.
- o Examining the effects of these processes and events on the performance of the disposal system.
- o Estimating the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events.

It is further required that the release estimates be incorporated into an overall probability distribution of cumulative release. To accomplish this, a probabilistic analysis for all applicable input parameters, including scenario occurrence, must be performed. The project is organized into scenario development, hydrology, geochemistry, and support activities.

The main activities of the scenario development program are formulation of credible scenarios, estimation of scenario probabilities, and development of consensus among project participants and review agencies. Scenarios will be divided into two groups: those that result in release due to natural processes; and those that result in release due to inadvertent human intrusion. Inadvertent human intrusions currently under consideration include single as well as multiple boreholes connecting the repository with water sources such as a hypothetical brine reservoir, the Culebra Dolomite member, and the Bell Canyon Formation.

The main activities of the hydrology program will be groundwater flow-path modeling, radionuclide transport modeling, and the determination of the flow rate of repository fluid entering the flow-paths for each scenario. A prerequisite to flow-path modeling will be the determination of the flow regime and the spatial distribution of aquifer parameters such as permeability and storativity. Once this is established, a groundwater flow model will be constructed. Geostatistical techniques such as kreiging will be applied to the appropriate parameters to determine the probability distributions. Either an analytical closed-form solution to the stochastically formulated partial differential equation of groundwater flow, or a deterministic numerical code in conjunction with a conditional simulation technique will be used. Codes currently being evaluated for use are SWENT and SWIFT II. To incorporate uncertainty, simulations using either Monte Carlo or Latin Hypercube techniques will be employed.

Radionuclide transport modeling will be performed using either the deterministic numerical models or an analytical stochastic approach. The result from either of these approaches will be a probability distribution of radionuclide release at each boundary point in the model at each time step up to 10,000 years.

Geochemical tasks include modeling potential sources of intruding water, modeling the repository environment, estimation of radionuclide solubilities, and modeling radionuclide sorption and precipitation reactions along potential flow-paths to the environment. The modeling tasks will be performed using the EQ3NR/EQ6 geochemical code which is a solubility/speciation/reaction path code capable of dealing with saturated brines. The dependence of modeling results on uncertainties in input parameters will be determined using sensitivity analysis techniques.

Potential sources of intruding water which will be considered are: Salado Formation water (fluid incisions, intergranular fluid, and crystallization fluid); a hypothetical brine reservoir below the repository; migration of water down the shaft/seal/disturbed rock system; and borehole connections with water-bearing units such as the Bell Canyon Formation.

Several options exist for the estimation of radionuclide solubilities in a brine environment. Two theoretical approaches under consideration are the Pitzer and ion hydration models; however, both of these approaches are limited by a current lack of data on the actinide elements. Natural analog investigations can be quite useful in a qualitative sense, but lack the site-specificity required for rigorous analysis. Existing experimental data on high-level waste/brine interactions performed by ONWI and other organizations will be evaluated for applicability to the WIPP project. The most useful data, however, would be from experiments performed using actual site-specific waste, groundwater, and barrier materials.

Geochemical reactions occurring along potential flow-paths to the environment such as sorption and precipitation will be evaluated using a combination of hydrologic and geochemical techniques. Radionuclide sorption processes will be coupled with the transport equation and precipitation of radionuclides will be modeled using a solubility/speciation mode.

Supporting analysis includes a variety of thermomechanical modeling activities which support the scenario development, hydrology, and geochemistry tasks. Examples of support modeling activities include modeling the temperature and pressure in the repository as a function of time, determining the temperature and pressure in the repository as a function of time, determining the temperature and pressure gradient surrounding the repository as a function of time, and determining the repository consolidation rate.

It is anticipated that the plan outlined above will yield the most accurate assessment of the performance of the WIPP repository that the current technological state-of-the-art will allow. The close integration of the above activities, coupled with the use of the latest advances in computer simulation and numerical modeling techniques, will ensure that the results of this project will be of value in determining compliance with 40 CFR 191.

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