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USE OF PERFORMANCE ASSESSMENT IN SUPPORT OF WASTE ISOLATION PILOT PLANT (WIPP) PROGRAMMATIC ACTIVITY PLANNING

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is being developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. A Compliance Certification Application (CCA) of the WIPP for such disposal was submitted to the U.S. Environmental Protection Agency (EPA) in October 1996, and was approved by EPA in May 1998. In June 1998, two separate, but related, lawsuits were filed, one against DOE and one against EPA. On March 22, 1999, the court ruled in favor of DOE, and on March 26, 1999, DOE formally began disposal operations at the WIPP for non-mixed (non-hazardous) TRU waste. Before the WIPP can begin receiving mixed (hazardous) TRU waste, a permit from the State of New Mexico for hazardous waste disposal needs to be issued. It is anticipated that the State of New Mexico will issue a hazardous waste permit by November 1999. It is further anticipated that the EPA lawsuit will be resolved by July 1999.

Congress (Public Law 102-579, Section 8(f)) requires the WIPP project to be recertified by the EPA at least as frequently as once every five years from the first receipt of TRU waste at the WIPP site. As part of the DOE's WIPP project recertification strategy, Sandia National Laboratories (SNL) has used systems analysis and performance assessment to prioritize its scientific and engineering research activities. Two 1998 analyses, the near-field systems analysis and the annual sensitivity analysis, are discussed here. Independently, the two analyses arrived at similar conclusions regarding important scientific activities associated with the WIPP. The use of these techniques for the recent funding allocations at SNL's WIPP project had several beneficial effects. It increased the level of acceptance among project scientists that management had fairly and credibly compared alternatives when making prioritization decisions. It improved the ability of SNL and its project sponsor, the Carlsbad Area Office of the DOE, to demonstrate the importance of ongoing scientific and engineering activities associated with the WIPP project. Finally, it provided objective documentation of the decision-making process for issues with an impact on safety at the WIPP, a critical topic for the general public and the regulatory agencies.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is located 26 miles east of Carlsbad, New Mexico, USA. The WIPP is a deep geologic repository located approximately 650 meters underground in Permian bedded salt.

Scientific investigations performed since 1974 have characterized the site, analyzed the condition of the waste, and identified the processes that may occur in the future. These investigations led to the development of mathematical and computer models that form the basis for probabilistic performance assessments (PAs) to evaluate future behavior of the WIPP while accounting for the uncertainties in the available models. Sandia National Laboratories (SNL) conducted a comprehensive probabilistic PA in 1996. The results from this PA were a significant contributor to the basis of the U.S. Department of Energy's (DOE) application for certification of compliance with 40 CFR Part 191 (1) and 40 CFR Part 194 (2), the radioactive waste disposal regulations of the U.S. Environmental Protection Agency (EPA). The 1996 PA is documented in the DOE's Compliance Certification Application (CCA) (3).

The EPA approved the CCA for the WIPP in May 1998. This approval concluded that the WIPP will comply with the EPA's radioactive waste disposal regulations and that the WIPP could begin disposing of radioactive transuranic (TRU) waste. In July 1998, the New Mexico Attorney General and other parties filed a lawsuit against the DOE. On March 22, the court ruled in favor of DOE, and DOE began disposing of non-hazardous TRU waste at the WIPP on March 26, 1999. The State of New Mexico regulates the hazardous waste component of mixed TRU waste. Before the WIPP begins receiving all TRU waste (hazardous TRU waste) the following issue must be resolved:

- Issuance of a Resource Conservation and Recovery Act (RCRA) permit by the State of New Mexico for hazardous waste disposal at the WIPP.

It is anticipated that the above issue will be resolved by November 1999, and the WIPP will then begin to receive all TRU waste from the DOE complex.

In addition, there is a pending lawsuit against the EPA and the impacts of this lawsuit on WIPP operations are indeterminate at this time. However, it is anticipated that the lawsuit against the EPA will be resolved by July 1999.

40 CFR Part 194 states that if the certification is issued, then the EPA will determine if the WIPP has remained in compliance with its environmental radiation protection standards at least once every five years after the initial receipt of waste for disposal at the WIPP. Since the EPA's approval of the CCA in May 1998, the WIPP project has begun to develop and implement DOE's recertification strategy, with SNL continuing to perform scientific research and development for the WIPP in support of the strategy.

As part of this strategy, a near-field systems analysis and a sensitivity analysis were conducted by SNL in 1998. The studies

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used PA, and the results of these studies were weighed by WIPP project management in setting the priorities for proposed scientific activities.

NEAR-FIELD SYSTEMS ANALYSIS METHODOLOGY AND RESULTS

Since the EPA's WIPP certification decision SNL has continued the development of more realistic and less conservative conceptual models for potential use in the first recertification. In 1998, SNL performed a systems analysis for the WIPP's near-field*, which encompasses the waste disposal area, the Salado Formation within the Land Withdrawal Area (LWA), and boreholes that are assumed to inadvertently intrude into the repository in the future.

Processes occurring within the near-field may cause radionuclide releases by three pathways: direct releases to the surface during drilling; groundwater releases to transmissive subsurface units through abandoned, degraded boreholes; and groundwater releases laterally across the LWA in the Salado Formation.

The methodology of the near-field systems analysis comprised three components. First, a more realistic integrated conceptual model (ICM) was developed for near-field interactions, which expands on the established baseline conceptual models presented in the CCA. Second, potential activities and other plausible outcomes that assist in the development or defense of the more realistic conceptual models were presented. Third, the plausible outcomes were evaluated in terms of tangible benefits to the WIPP program.

The near-field systems analysis developed ICMs of near-field conceptual models using text and influence diagrams. Evaluation criteria were developed according to which proposed scientific and engineering activities could be related to high-level goals of the project. The ICMs were used as a guide in evaluating the extent to which proposed activities could impact high-level goals. A prioritization of activities was constructed, based on the total impacts of proposed activities on the project goals as measured by evaluation criteria.

Identification of Near-Field Characteristics

The initial stage of the systems analysis methodology is the identification of near-field characteristics that are known to be important for near-field performance. A large body of information is available to guide the selection of these characteristics, which is included in the 1996 PA for the CCA (3) and its associated uncertainty and sensitivity study (4). In addition, the development of a mechanistic model for spalling, the expert elicitation on particle size distribution for spalling releases from the disposal room, and studies of the chemical behavior of MgO also provided relevant information on characteristics that are critical for determining performance.

Based on this information, five characteristics were identified that have major impacts on near-field performance:

Actinide Source Term (or near-field source term). The actinide source term includes the concentrations of dissolved and colloidal actinides, transport through advection and diffusion, and physical and chemical retardation. The actinide source term is an important characteristic because the magnitude of radionuclide release through any fluid pathway is related to aqueous actinide concentrations.

Waste Gas Pressure. This term refers to the gas pressure within the repository. It is a function of gas generation from biodegradation and corrosion, as well as the pore space available for gas. Each of these processes and characteristics depends on brine saturation, leading to a complex coupling between fluid inflow/outflow and pressure in waste disposal panels. Repository pressure is an important characteristic for all release mechanisms except cuttings and cavings. It has a central role in repository performance.

Waste Brine Saturation. This is a measure of the "wetness" of the panels and disposal rooms. Brine saturation is an important parameter for direct brine release.

Waste Strength. This is a key mechanical parameter for direct releases from a heterogeneous mix of organics, inorganics, and solidified sludges. Waste strength at any particular time will be a function of chemical and physical processes, including biodegradation, MgO hydration, salt precipitation, MgCO3 precipitation, waste compaction, and brine saturation.

Borehole Properties. These include the short and long-term flow properties of a borehole after an intrusion and also the drilling and plugging practices in the Delaware Basin (where the WIPP is located) that influence these properties.

Integrated Conceptual Models (ICMs) of Near-Field Processes

An ICM of the near-field describes the important features, events and processes (FEPs) that could occur within the boundaries of the near-field. In this systems analysis, we used eight fundamental elements to define the near-field ICMs. Five of the eight ICMs are the important near-field characteristics that have major impacts on performance, as described in the previous section. The other three ICMs are direct releases to surface; releases to units other than the Salado Formation (in which the repository is located); and Salado Formation releases. Together, the eight near-field ICMs form a single ICM for the entire near-field.

Influence Diagrams

In the near-field systems analysis, we used influence diagrams as a tool for developing the ICM of the near-field. A description of a conceptual model is most effective when both text and figures are used appropriately to convey the processes and influences being considered. Influence diagrams illustrate the manner in which the results of a particular process or event affect the occurrence or progress of a different process. The diagrams developed attempt to show relationships among processes in the disposal system as they will really occur, rather than how disposal system processes were approximated in previous PAs or will be approximated in future PAs. By presenting major processes as they are perceived to occur rather than how they have been modeled in the past, the influence diagrams can serve as an effective tool for predicting how scientific and engineering activities could impact past PAs, resulting in improved predictions of performance. The influence diagrams comprise four components as shown in Fig. 1.

* Near-field - The waste, excavations, engineered barriers, and Salado Formation extending to the land-withdrawal boundary.

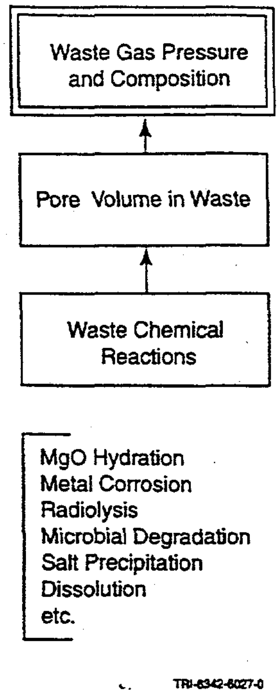

Fig. 1. Structure of an influence diagram.

The highest level represents the eight near-field ICMs, such as waste gas pressure and composition (Fig. 1). The next level represents an ICM subsystem, such as pore volume in waste. The bracketed text indicates the conceptual models for individual processes, for example, fracturing in the host rock of the repository. Finally, the arrow indicates an influence between two elements. The arrowhead indicates the direction of the downstream effects.

Evaluation Criteria

A set of six criteria were defined to evaluate the potential benefits of improved conceptual and mathematical models and data for the near-field. The evaluation criteria were developed to represent documented objectives of the WIPP project in concise ways. The following six evaluation criteria were used in the near-field systems analysis:

1. Impact on prediction of long-term performance
2. Impact on uncertainty
3. Impact on public confidence
4. Cost and schedule impacts
5. Worker and public risk impacts
6. Relevance to emerging issues, waste management, and other facilities

The first two criteria relate to the predictions of long-term performance generated by the probabilistic PAs. A reduction in predicted release may result from incorporating models that more realistically depict actual processes. Reduced uncertainty in results may occur by increased realism of models and in reducing the ranges of uncertain, randomly selected input variables. The third criterion, improved public confidence, is assessed with respect to increasing the likelihood of favorable reviews from external peer review groups, such as the U.S. National Academy of Sciences, the EPA, the International Atomic Energy Agency or Nuclear Energy Agency, the independent Environmental Evaluation Group, or other external peer reviews. The fourth, cost and schedule impacts, provides information about these factors to the program manager that may impact prioritization. The fifth, worker and public risk impacts, is related to the potential of an activity to reduce the potential exposure of workers or the public to disposal-related hazards, chiefly radiation exposure. The last criterion, relevance to emerging issues, waste management, and other facilities, allows other impacts to be weighted in the overall decision.

The relevance of proposed activities to the evaluation criteria was assessed subjectively as high, moderate, and none, based on the experience of the authors and contributing scientific staff for the baseline conceptual and mathematical models (used in the 1996 PA for the CCA), sensitivity results from the baseline model and previous PAs, comments from reviewers and external peer groups, and expert knowledge in relevant technical fields. Costs and duration were quickly and subjectively estimated based on the experience of the authors and contributing staff. Only activities with at least one high impact were seriously considered for funding. Activities with multiple high impacts received higher prioritization.

SUMMARY OF NEAR-FIELD SYSTEMS ANALYSIS

The near-field systems analysis evaluated 89 activities. Table I shows a portion of the results of the near-field systems analysis.

Four activities were assessed to have a high benefit in four or five categories: 1) accounting for water uptake by MgO reactions, 2) accounting for variability in the biodegradability of cellulose, rubbers, and plastics, 3) improving models of the disturbed rock zone (DRZ), and 4) demonstrating waste strength.

SENSITIVITY ANALYSIS AND PERFORMANCE ASSESSMENT

A sensitivity analysis was performed by SNL in 1998. This is the first sensitivity analysis of the WIPP since the EPA's certification was issued. The analysis (called ASA98, or annual sensitivity analysis 1998 [5,6]) was conducted for two main purposes: 1) to demonstrate the readiness of SNL to perform total system performance assessments and sensitivity analysis and 2) to evaluate the impact of suggested experimental activities (and new data) and more realistic conceptual models on long-term performance.

The PA calculation strategy for ASA98 is similar to that in the CCA. The disposal system components and subsystems were modeled in separate tasks to calculate consequences for the undisturbed scenario and for the disturbed, or human intrusion, scenarios, i.e., E1 (borehole intersects the repository and a brine reservoir) and E2 (borehole intersects the repository but does not intersect a brine reservoir). Figures 2 and 3 show the PA computational model components used in the CCA and ASA98. Code versions of CCA and ASA are documented in References 3 and 5, respectively.

The main differences between these two models are as follows:

1. There were no direct release calculations performed in ASA98 because analysis of predicted repository conditions showed that conditions leading to such releases were unlikely; hence no complementary cumulative distribution functions (CCDFs) were constructed.

TABLE I

Examples of Benefits of Potential Activities (6)

No.	Description of Activity	Estimate of Impact from Performing the Activity[a]					
		Performance	Uncertainty	Public. Conf.	Safety	Cost and Schedule[b]	Emerging Issues
1	Add Water Balance for MgO Reactions	H	M	H	M	$$$, 3 yr	H
2	Add Multiple Biodegradation Rates	H	H	M	H	$$, 2 yr	H
3	Include Biodegradation in Repository Water Budget	L	L	N	N	$, 1 yr	N
4	Develop Corrosion Kinetic Expression	M	L	L	N	$, 1 yr	L
5	Re-estimate Surface Area of Steel	M	L	L	N	$, 1 yr	L
6	Evaluate Importance of Radiolysis	L	L	M	N	$, 2 yr	N
7	Calculate Initial Conditions in DRZ	H	H	H	N	$, 2 yr	H
8	Rock Mechanics for DRZ Healing	H	H	H	N	$, 1 yr	H
9	Evaluate Effects of Molecular Diffusion on Chemical Processes	N	N	H	N	$, 1 yr	M
10	Analytical Solution for Salado Transport	L	N	M	N	$$$, 3 yr	H
11	Tensile Strength of the Waste	H	H	H	N	$$$$, 3 yr	H
12	Shear Strength of the Waste	H	H	H	N		M

[a] H=high, M=moderate, L=low, N=no or negligible impact on the activity

[b] $ = ½ full-time equivalents (FTEs), $$ = 1-2 FTEs, $$$=3-4 FTEs, $$$$ > 4FTEs

2. The subsurface transport model component in the CCA (SECOTP2D) was replaced by TRACKWAY and SBI.

In addition to these differences, there were changes to other model components and input parameter values, as summarized in the following section.

Summary of Changes in Models and Parameter Values Considered in ASA98

Key Changes of PA Component Models

1. Salado Flow (BRAGFLO). BRAGFLO performs a three-dimensional coupled simulation of gas generation, repository creep closure, and brine and gas flow in the near-field under undisturbed and disturbed conditions. In the CCA, the Salado flow was calculated with a two-dimensional version of BRAGFLO.
2. Salado Transport (NUTS). NUTS simulates three-dimensional transport in the near-field and up the intrusion borehole to the Culebra Dolomite Member of the Rustler Formation (located above the Salado Formation) using the BRAGFLO flow field for undisturbed conditions. In the CCA, a two-dimensional version of NUTS was used for the Salado transport.
3. Brine Mixing Calculations for Actinide Source Term (NUTS). The quantity of Salado and Castile brine in the repository was tracked with the NUTS code in ASA98, and the appropriate source term concentration was correlated with the mixtures by a lookup table. In the CCA, brine was assumed to be derived from the Salado for undisturbed conditions, and from the Castile, or a source compositionally similar to the Castile, for disturbed conditions.
4. Culebra Transport (TRACKWAY, SBI, and STAMMT-L). TRACKWAY performs particle track calculations to convert SECOFL2D flow paths to one-dimensional curvilinear flow paths at 11 potential borehole source locations. SBI uses the 11 pathways generated by TRACKWAY to simulate one-dimensional transport (unit source) in the Culebra. STAMMT-L then simulates one-dimensional transport in the Culebra with a multi-rate diffusion model for one pathway. SECOTP2D was used in the CCA for Culebra transport.

Key Changes of PA Input Parameter Values

1. Gas generation due to microbial degradation for cellulose was made more realistic in ASA98 compared to the CCA.
2. The permeability of panel closure was sampled between 2.00×10^{-21} and 10^{-17} m^2, and the permeability of the DRZ was sampled between 10^{-17} to 10^{-14} m^2. In the CCA, these two permeabilities were both a constant value of 10^{-15} m^2.
3. Sampling a new parameter value between 2 and 100 in the existing gas-generation equations approximated the

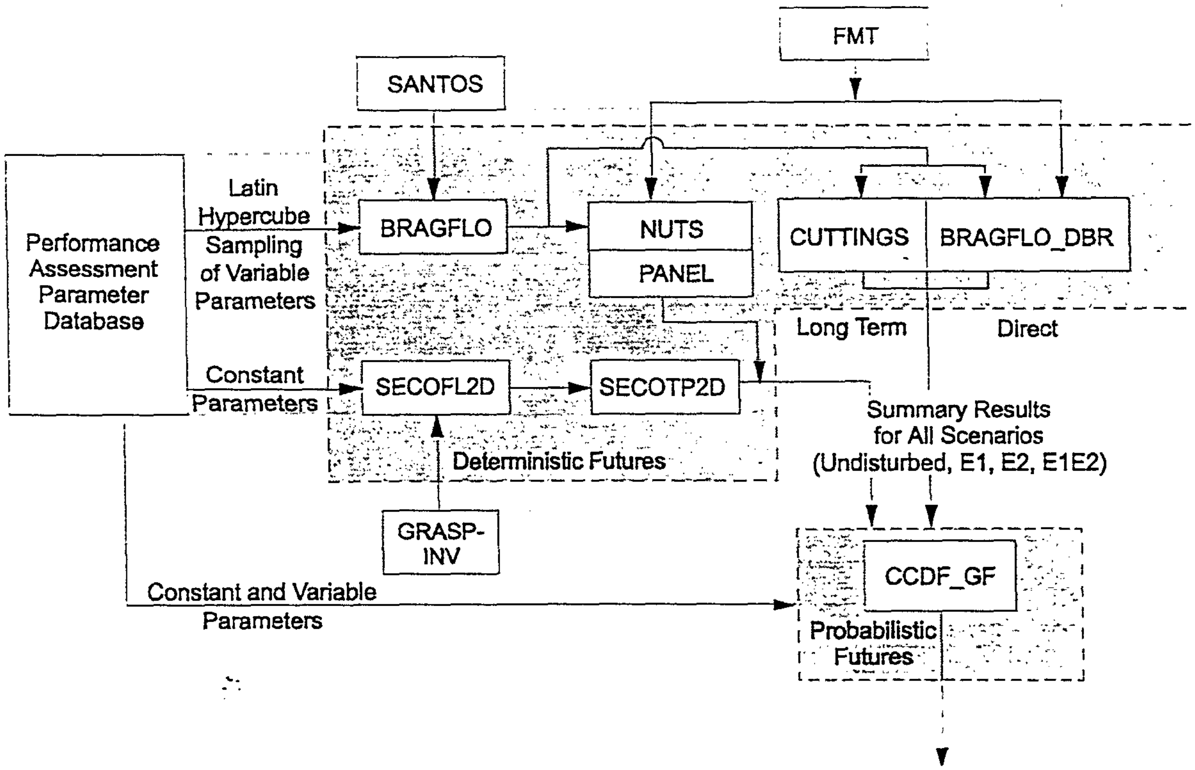

Fig. 2. Model components and their relationships as used in the CCA PA calculation structure (3).

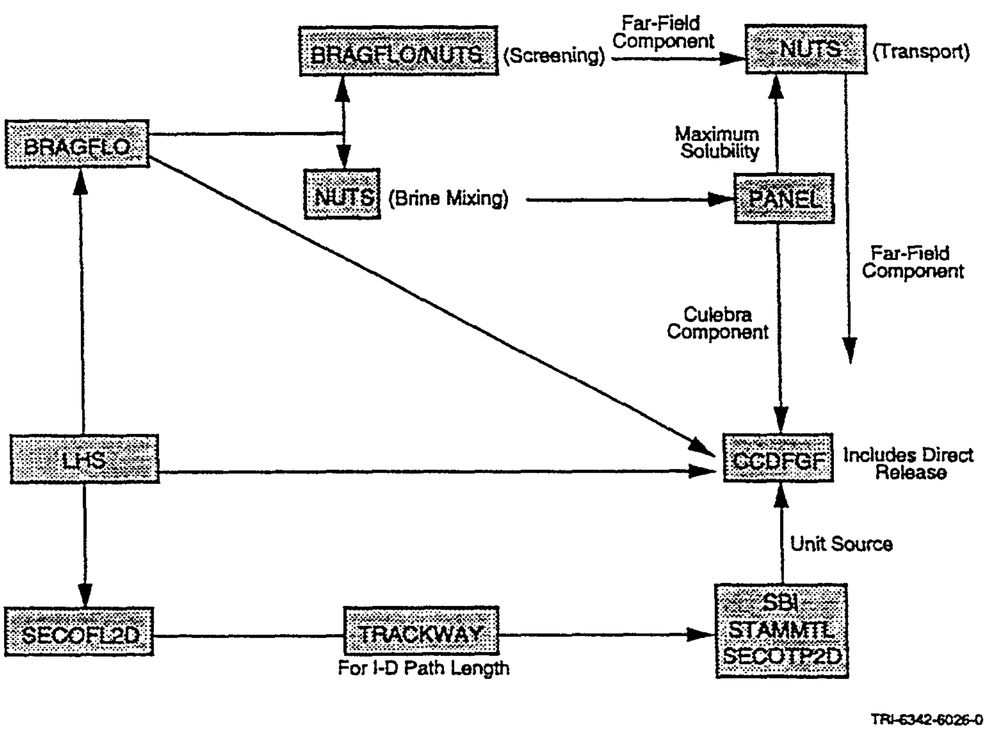

Fig. 3. Model components and their relationships in the ASA98 calculation structure (5).

effects of water removal from MgO hydration. If MgO hydration were not accounted for (as in the CCA), the value of the corrosion stoichiometric coefficient for water consumption would be 2. The larger values for the MgO hydration were intended to preferentially consume H_2O by hydration of MgO.

4. Actinide solubility was correlated with the calculated brine mixture of brine from the Salado and Castile Formations. This method is more realistic because the waste in the repository would contain a different mixture of these two types of brine at any time in the simulation. In the CCA, we assumed that the brine in the

repository is usually Salado brine when the intrusion occurs, which is a conservative assumption since the actinide solubility is higher for the Salado brine.

Uncertainty and Sensitivity Analysis for ASA98

The sensitivity of CCDFs to uncertain input parameter values can be assessed with partial rank correlation coefficients. The importance of the input parameter uncertainties is analyzed using a stepwise regression analysis technique. The uncertainty and sensitivity analysis helps explain why analysis outcomes behave in particular ways and also provides an important check on the correctness of individual results.

In ASA98, there were 52 Latin hypercube sampled (LHS) parameters. A total of 100 LHS random realizations were constructed and used in the ASA98 calculations. The importance of these uncertain input parameters is discussed in the following section.

Summary of ASA98 Performance Assessment Results

The ASA98 parameter and model implementation changes that had the most significant impact on repository long-term performance relative to the CCA were

1. Stoichiometric factor for MgO hydration
2. Reduced DRZ volume
3. Mean permeability of the DRZ
4. More effective panel closure (panel permeability)

These changes significantly reduced those releases that depend upon repository pressure and saturation (i.e., all releases except cuttings and cavings).

CONCLUSION

The SNL WIPP project uses a decision-analysis approach to prioritize plausible and feasible scientific and engineering activities. In the 1999 fiscal year (FY99), the prioritization method drew upon two different analyses extensively as a source of documentation and input to the prioritization process. The near-field systems analysis described a systematic evaluation of the WIPP disposal area and the Salado Formation, systematically and qualitatively evaluating all the proposed scientific activities against six criteria. The ASA98 used the total system performance assessment analysis, coupled with uncertainty/sensitivity analysis techniques, to quantitatively rank the important input parameters relative to the long-term performance objectives of the WIPP repository. Independently, these two different analysis techniques both concluded that the most important scientific activities for the WIPP recertification are 1) MgO hydration, 2) DRZ properties, and 3) waste disposal panel permeabilities.

The decision-analysis technique used for the FY99 prioritization and budget planning process was subjective but contained both qualitative and quantitative information as supporting data (i.e., near-field systems analysis and ASA98). It provided objective documentation of the reasoning and rationale for choosing to pursue some activities and not others. The use of these analyses had several effects. First, it increased the level of acceptance among project scientists that management had fairly and credibly compared alternatives when making prioritization decisions. Second, it improved the ability of SNL and its project sponsor, the Carlsbad Area Office of the DOE, to demonstrate the importance of ongoing scientific and engineering activities associated with the WIPP project. Finally, it provided objective documentation of the decision-making process for issues with an impact on safety at the WIPP, a critical topic for the general public and the regulatory agencies. SNL plans to continue to use these techniques to prioritize and plan the scientific activities for the WIPP project in the future.

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