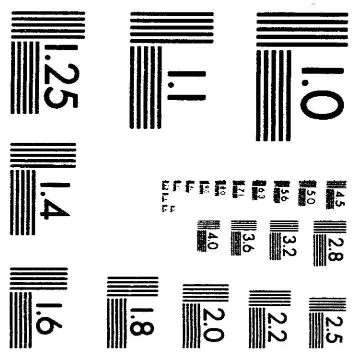

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USING PERFORMANCE ASSESSMENT FOR RADIOACTIVE WASTE DISPOSAL DECISION MAKING - IMPLEMENTATION OF THE METHODOLOGY INTO THE THIRD PERFORMANCE ASSESSMENT ITERATION OF THE GREATER CONFINEMENT DISPOSAL SITE [a]

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ABSTRACT

The U.S. Department of Energy is responsible for the disposal of a variety of radioactive wastes. Some of these wastes are prohibited from shallow land burial and also do not meet the waste acceptance criteria for proposed waste repositories at the Waste Isolation Pilot Plant (WIPP) and Yucca Mountain. These wastes have been termed "special-case" waste and require an alternative disposal method. From 1984 to 1989, the Department of Energy disposed of a small quantity of special-case transuranic wastes at the Greater Confinement Disposal (GCD) site at the Nevada Test Site. In this paper, an iterative performance assessment is demonstrated as a useful decision making tool in the overall compliance assessment process for waste disposal. The GCD site has been used as the real-site implementation and test of the performance assessment approach. Through the first two performance assessment iterations for the GCD site, and the transition into the third, we demonstrate how the performance assessment methodology uses probabilistic risk assessment concepts to guide effective decisions about site characterization activities and how it can be used as a powerful tool in bringing compliance assessment decisions to closure.

I. INTRODUCTION

The U.S. Department of Energy's Nevada Operations Office (DOE/NV) has disposed of a small amount of transuranic waste within the Radioactive Waste Management Site (RWMS) located in Area 5 of the Nevada Test Site (NTS). The waste has been disposed of using a concept termed Greater Confinement Disposal (GCD). Sandia National Laboratories, under contract to the DOE, is conducting analyses to assess the likelihood that the GCD facility will comply with the Environmental Protection Agency standards for disposal of transuranic waste, high-level waste, and spent fuel (40 CFR 191)[1]. For the GCD waste to remain emplaced and be considered permanently disposed of, the performance assessment results must show compliance with 40 CFR 191.

A. Introduction to the Performance Assessment Methodology

The methodology developed by Sandia National Laboratories for performance assessment of high-level[2,3] and low-level[4] nuclear waste disposal sites has provided the foundation to assess GCD compliance with 40 CFR 191. The same methodology is being applied to assess risk associated with environmental restoration sites and to help guide site remediation.[5] The primary components of the methodology are (1) identification of performance measures and analysis objectives, (2) system description, (3) scenario development and screening, (4) conceptual model development, (5) consequence modeling, (6) uncertainty analysis, (7) sensitivity analysis, and (8) data worth analysis. As will be discussed in this paper, each component plays an integral role in making decisions regarding site characterization activities and making decisions that bring the process to closure.

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The performance assessment methodology is an iterative approach that uses probabilistic risk assessment concepts to guide decision making about data collection and regulatory compliance. In general, this is done by careful upfront analysis of the regulatory objectives, combined with an approach that focuses technical analysis and use of available resources toward addressing those objectives. That is, the methodology implicitly provides a path toward closure of defensible regulatory decisions.

Although EPA's 40 CFR 191 mandates a probabilistic analysis such as the one employed by the Sandia methodology, we maintain that it is appropriate to conduct uncertainty analysis together with sensitivity analysis at any site using relevant regulations as the performance measure. The results of probabilistic analyses provide explicit representation of the uncertainty associated with site performance and therefore provide confidence in the decision making process. Furthermore, we advocate the use of a conservative bias intentionally incorporated into the analysis to increase confidence in the regulatory decision. Finally, the results of such analyses can be used to prioritize and effectively allocate resources for data collection at the site.

B. Overview of the Performance Assessment Methodology Applied at the GCD Site

The first step in the analysis of the GCD facility was to conduct a preliminary (or first-iteration) performance assessment using existing information. The main objectives were to (1) evaluate the likelihood of success in meeting regulatory requirements and, (2) identify the most important factors affecting the overall performance of the site to guide future data collection. From examination of existing site data, a conceptualization of the important processes controlling radionuclide migration was developed, and distributions for input parameters were created. Only existing data was used for this analysis. No new data were collected. Due to the paucity of existing data, several of the input parameters were very uncertain. Monte Carlo simulation was used to propagate parameter uncertainty to uncertainty in releases of radioactivity to the environment. Subsequent to the calculation of releases, sensitivity analysis was used to identify the most important parameters. Site characterization activities were then carried out to reduce the uncertainties in those parameters and processes found to be most important. As a result of the site characterization, parameter distributions were revised and some pathways (or components thereof) were eliminated. The second iteration followed using the revised transport models and parameter distributions. Sensitivity analyses again were conducted to identify the most important processes.

Note that neither the first nor the second performance assessment iteration was a complete performance assessment as required by 40 CFR 191. That is, the effects of future plausible disruptive events and processes were not addressed in either iteration. The primary focus of the ongoing third iteration is to incorporate the consequences and probabilities of these disruptive processes as well as implement necessary changes to the models used in the second iteration. Further details of the performance assessment analyses for GCD will be discussed later.

II. SITE DESCRIPTION

The GCD facility is a waste disposal site located at the Radioactive Waste Management Site on the Nevada Test Site. The GCD site is so named because the disposal strategy is one in which the waste is placed at the bottom of 36.6 m (120 feet) augered boreholes to provide greater confinement of the wastes than the shallow land burial pits that are also used at the RWMS.

The NTS is located in southeastern Nevada, approximately 110 km (70 miles) northwest of Las Vegas, and is in the southern part of the Basin and Range geologic province. The GCD site is in Frenchman Flat basin, which is on the eastern border of the NTS, as shown in Figure 1.

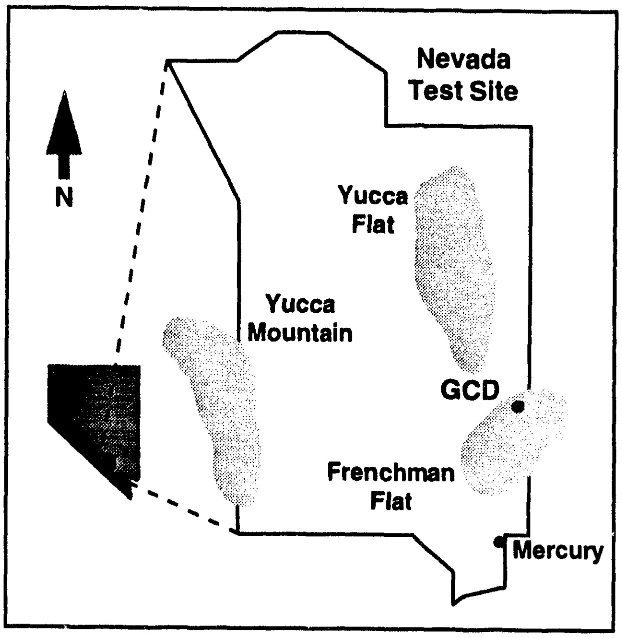

Figure 1. Location of the GCD Site [modified from Price et al.[6]]

The climate of Frenchman Flat is very arid; mean annual precipitation is approximately 10 cm (4 in), equally distributed between winter frontal storms and summer thunderstorms. The vast majority of the precipitation is returned to the atmosphere via evapotranspiration; very little penetrates the ground to depths beneath plant roots. Vegetation is sparse, consisting mostly of creosote bush along with other low shrubs and grasses.

At the location of the GCD boreholes, the basin is filled with alluvium to a depth of approximately 460 meters (1500 feet); the upper 235 meters (770 feet) are unsaturated and the Valley Fill alluvial aquifer occupies the lower 225 meters (730 feet). Therefore, the GCD waste resides approximately 200 meters (650 feet) above the water table. Tertiary tuffs underlie the alluvium. The upper portion of the tuff sequence is composed predominantly of fractured, vitrified tuffs which serve as an aquifer in Frenchman Flat basin. The lower portion of the tuff sequence is composed largely of unvitrified tuffs which form an aquitard between the aquifers of the basin and the regional carbonate aquifer beneath. A very thick layer of paleozoic carbonates comprise the lower carbonate aquifer. Leakage from the closed basin aquifers through the tuff aquitard is drained by this regional aquifer.[7] A cross section of site is shown in Figure 2.

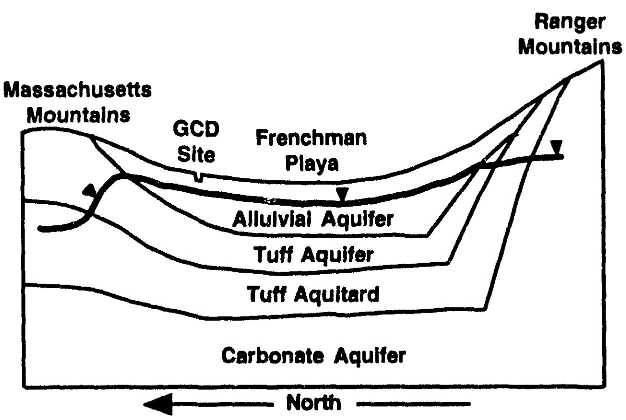

Figure 2. Assumed Stratigraphy at the GCD Site, Frenchman Flat, Nevada Test Site [modified from Price et al.[6]]

The GCD boreholes are 3 meters (10 feet) in diameter and 36.6 meters (120 feet) deep. Waste is emplaced in the bottom 15.2 meters (50 feet) of the borehole and the remaining 21.3 meters (70 feet) from the top of the waste to the land surface is back-filled with sifted, native alluvium. A diagram of a borehole is given in Figure 3. The bottom of each borehole is approximately 200 meters (650 feet) above the water table.

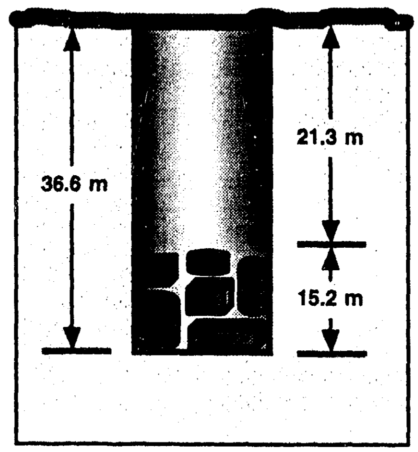

Figure 3. Schematic Diagram of Typical GCD Borehole [modified from Price et al.[6]]

The waste under consideration in the GCD facility 40 CFR 191 performance assessment consists of various isotopes of plutonium and uranium (approximately 1200 Ci), along with their decay products. All these radionuclides were disposed of as solids.

III. PERFORMANCE ASSESSMENT METHODOLOGY

The methodology being implemented to assess performance of the GCD facility is a highly integrated, interconnected set of procedures or components. Separations between components are often not distinct. For example, uncertainty analysis spans site description, conceptual model development, scenario development and screening, and consequence modeling. Rather, the methodology is divided into components for the sake of clarification of discussion, process description and management, and tracking of analyses. In the discussion that follows, each of the components that go into the methodology are discussed. They are presented in the order in which they are generally applied during the performance assessment process. The pieces are then synthesized into an integrated, iterative methodology which provides the foundation for decision making. The discussion of the integrated methodology follows the summary of components.

A. Summary of components

A short discussion of each of the components that comprise the Sandia performance assessment methodology is provided below along with specific role each plays within the GCD project.

1. Identification of performance measures and analysis objectives. This component defines the regulatory environment through identification of applicable regulatory performance measures and, in turn, defines the objectives of the analysis. In terms of regulatory structure, the performance of the GCD facility is compared against the EPA regulation for disposal of spent fuel, transuranic waste, and high-level waste, 40 CFR 191[1]. The overall objective of the performance assessment analysis is, simply stated, to provide the DOE with the technical basis to make a decision regarding regulatory compliance in the most efficient way possible. As a result, an internal objective of the process is to use the regulatory performance measures to focus model development and data collection.

The regulation contains three quantitative requirements: individual protection, groundwater protection, and containment. Results of the GCD performance assessment have been compared against these three quantitative requirements, but the results for only one, the containment requirements, are discussed in this paper. All other regulations that might apply to the GCD site (e.g., Resource Conservation and Recovery Act, DOE Orders, Safe Drinking Water Act) are not part of the 40 CFR 191 performance assessment, but will also have to be identified and evaluated. Deciding which regulations apply to the site and how they would be implemented is beyond the scope of this paper.

The containment requirements are probabilistic in nature; they limit the probability of cumulative releases, in terms of curies, of radionuclides to the accessible environment over 10,000 years. The accessible environment is defined to include the ground surface and any point in the subsurface that is laterally beyond five kilometers from the disposal site. The cumulative release for each radionuclide is normalized by the release limits listed in 40 CFR Part 191 which are based on the amount of disposed waste. The normalized release estimates are summed over all radionuclides to produce the regulation's measure of release, referred to as "EPA sum". The containment requirements state that the EPA Sum must have a likelihood of less than one chance in 10 of exceeding one and a likelihood of less than one chance in 1000 of exceeding 10. The final result of these calculations is a complementary cumulative distribution function (CCDF), a curve that is plotted with probability on the vertical axis and EPA Sum on the horizontal axis. Examples of CCDF curves can be found in Figure 5. A curve that passes through the cross-hatched region indicates a violation of the EPA's containment requirements while one that does not pass through the cross-hatched region indicates compliance with the requirements.

2. System description. System description is a general category in the methodology which is repository and site specific, and is the step that sets the physical basis for conceptual model development. It involves the physical description of the characteristics of the waste, the engineered facility, and the geologic site. Generally, system description is the type of information given in the SITE DESCRIPTION section above.

3. Scenario development and screening. The high-level waste standard (40 CFR Part 191) requires analysis of "all significant processes and events that may affect the disposal system".[1] Although there will be only one progression of events and processes, we do not know what that progression will be. Therefore, all plausible future states of the disposal system, called scenarios, are considered in a performance assessment.[8] For our methodology, each scenario represents one of the possible combinations of events and processes. A probability of occurrence is estimated for each scenario so that the consequence of every scenario can be folded into a single CCDF.

In the first performance assessment iteration, limitations were imposed on the scenario analysis. First, only three scenarios were to be included in the analyses (in addition to the base case scenario in which present-day conditions continue). These three scenarios, climate change, erosion, and human intrusion, were chosen through a screening procedure based on likelihood and consequence. Secondly, the probabilities of occurrence were not to be calculated for scenarios. Therefore, each scenario had its own CCDF; results of consequence analyses were not combined into one CCDF representing all scenarios. After the first iteration, a formal scenario development and screening was initiated. The screening was not scheduled to be completed until after completion of the second performance assessment iteration. Therefore, in the second iteration, no disruptive scenarios were included; that is, only the revised base case was analyzed. The third iteration will include disruptive future events and processes in its analysis.

4. Conceptual Model Development. Because of the complexity of the geologic systems of concern, and the large temporal and spatial scales being evaluated, modeling is the only practical means by which to assess system performance. Furthermore, because of the large uncertainties associated with these types of systems, it is likely that several plausible alternative conceptual models may exist.

A conceptual model is simply a list of assumptions or simplifications used to describe a system for a given purpose. For waste disposal regulatory decision making, both the regulatory and physical information are critical in the conceptual model development process. In general, the conceptual model development procedure includes (1) identifying processes and pathways that are associated with scenarios, and (2) developing conceptual models, based on assumptions of system characteristics and guided by the regulatory objectives, to describe those processes. Conceptual models provide the basis for the development of mathematical and numerical models.

The treatment of uncertainty associated with conceptual models in the performance assessment process is discussed under Item 6, Uncertainty Analysis.

5. Consequence modeling. Consequence modeling involves the implementation of models to assess the performance of the site, and is inextricably linked to several of the other components. The process includes developing mathematical equations to describe the processes quantitatively, and solving these equations (numerically or analytically) to generate consequence realizations. The mathematical models are derived directly from the conceptual models developed under Item 4. The execution of multiple realizations in a probabilistic framework is guided by the uncertainty analysis in Item 6 below.

6. Uncertainty analysis. EPA's 40 CFR 191 requires that all sources of uncertainty be included in a performance assessment. The types of uncertainty associated with a performance assessment have been broken into three general categories[9,10]: (1) uncertainty in the future state of the disposal system, (2) model uncertainty, and (3) data and parameter uncertainty. Methods for including uncertainty in the future state of the disposal system have been addressed by Cranwell *et al.*[8], who developed the scenario development and screening methodology discussed under Item 3 above.

Treatment of model uncertainty includes both the development of alternative conceptual models and the propagation of the uncertainty through the consequence analysis using mathematical and numerical models. The performance assessment methodology we describe herein treats conceptual model uncertainty through the development and use of conceptual models that are conservative relative to the existing site information. That is, the analysis uses models that consistently overpredict releases in relation to what the actual release might be. The reasoning behind this is that, if it can be demonstrated that the conservative model complies with the regulations, then it follows that the actual site should also comply.

When dealing with geologic systems, and because we cannot know the future, a realistic conceptual model is not attainable. Rather, conservative alternative conceptual models are developed to compensate for the inherent lack of knowledge. These are evaluated, and the more conservative one retained for the final decision analysis. By doing this, the results of the analysis are by no means a prediction; the analysis only states that the results are overestimates of actual releases. The conservative assumptions are relaxed if the model indicates noncompliance and if defensible site information can be obtained that allows this relaxation of conservatism.

Because uncertainty exists in all phases of model development (including conceptual, mathematical and numerical model development), each must be considered in the final evaluation. During each step of the process, where the analyst is uncertain, a conservative bias should be introduced if possible. For example, conceptual models are often simplified because of mathematical or numerical constraints. In this case, the new, simplified conceptual model would be the basis for decision making.

Treatment of parameter uncertainty includes quantification and propagation of uncertainty. Quantification of parameter uncertainty is generally handled by developing probability density functions (PDFs) for parameters. The development of PDFs is closely related to model uncertainty in that the PDF in and of itself represents an assumption about the system, and because the parameter values used to define the PDF are almost invariably derived through interpretation of data measurements using modeling assumptions. Therefore, to be consistent with the approach used in treatment of model uncertainty, if defensible site information exists, then the PDF is based on that information. If the site information about a given parameter is uncertain, then an intentionally conservative PDF (assuming this can be defined *a priori*) is used for that parameter. For uncertain parameters however, ultraconservative PDFs (e.g., deterministic, single value) are not used in the initial stages because this would not allow for meaningful sensitivity analyses that follow. If a conservative PDF cannot be defined *a priori*, then an unbiased PDF is used. Again, the conservative assumptions are relaxed under the same conditions as they are for models.

Propagation of data and parameter uncertainty is comparatively straightforward. Methods for propagating uncertainty in data and parameters have been presented by many authors.[3,11,12,13,14] For the GCD performance assessment analyses, Monte Carlo simulation has been used to propagate data and parameter uncertainty to results of analyses. The Latin Hypercube Sampling (LHS) technique[15] was used to obtain samples for the Monte Carlo simulations because using LHS reduces the number of samples needed to span the range of uncertainty in data and parameters.

The results of uncertainty analysis and consequence modeling provide the necessary information for compliance assessment decision making. By using the results in a sensitivity analysis, decisions about follow-on data collection can be made.

7. Sensitivity analysis. In general, sensitivity analyses are performed to determine the influence of specific parameters or processes on the output of the model.[3] The results of a sensitivity analysis identify which parameters or models have the greatest influence on the model results. This information can then be used to guide data collection and model development efforts, where reduction of uncertainty associated with the most sensitive parameters or processes will reduce uncertainty associated with the assessment results. Within the performance assessment methodology, the important parameters and models are defined to be those that are both uncertain and lead to noncompliance. That is, both are necessary conditions for a given parameter or process to be investigated further. For example, if a parameter is certain and is sensitive enough that the value of the parameter leads the results to either noncompliance or compliance, additional information about that parameter will not add confidence to the regulatory decision. If a parameter is uncertain, but the results still indicate compliance, additional information does not add value in that the regulatory decision will not change.

This use of sensitivity analysis forms the basis for our underlying philosophy that performance assessment is an iterative process in which the performance assessment results drive subsequent data collection and in turn, the new data is incorporated into subsequent iterations of the performance assessment. Furthermore, it provides an explicit link between data collection and regulatory compliance assessment.

8. Data worth analysis. Data worth analysis evaluates the relative costs and benefits of further data collection. The analysis only has real application to those parameters and processes that are defined, by the criteria discussed above, to be important. In terms of decision making and for parameters that are unimportant, the costs are finite and the benefits are zero. Under certain conditions, prohibitive costs or technological constraints may preclude the acquisition of additional data. If this is indeed the case, then the site should be abandoned.

B. Performance Assessment Methodology Applied to Decision Making

Performance assessments are required for evaluating the suitability of radioactive waste repositories to isolate waste from the accessible environment. The purpose of this paper is to advocate a performance assessment approach in which (1) the methodology implicitly provides closure to the regulatory compliance decision, and (2) iterative performance assessment calculations guide the collection of site characterization data, and in turn, new site characterization data is incorporated into each successive iteration of the performance assessment calculation. Several authors[3,13] have proposed use of an iterative approach to performance assessment. In this study, we have implemented an iterative approach at an actual radioactive waste disposal site.

The integration of the performance assessment components into a decision making framework is shown in Figure 4. The process implicitly facilitates two types of decisions: decisions regarding regulatory compliance and decisions regarding site characterization data collection. Prior to entering the process flow shown in Figure 4, the regulatory framework and performance measures (component 1) are defined. This is a component that remains fixed throughout the process. Using information derived from the system description (component 2) and performance measures, the iterative process flow begins with the development of conceptual models (component 4) that are simple and are conservative relative to the existing site information. Conceptual models are developed for each scenario (component 3). These models are then carried through a consequence modeling (component 5) sequence that incorporates uncertainty (component 6) in parameters and uncertainty in the future state of the system. Recall that the treatment of conceptual model uncertainty has been addressed through the development of conservative models. If alternative conceptual models exist, and neither can be demonstrated to be more

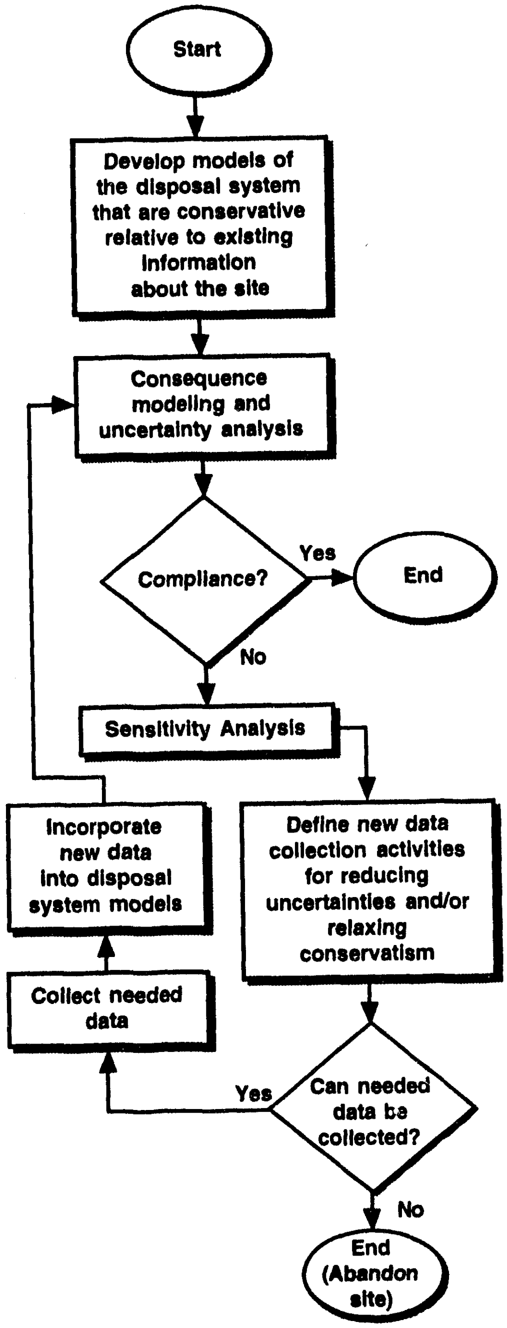

Figure 4. GCD Performance Assessment Process

conservative *a priori*, then all models are carried through the analysis and the most conservative model that cannot be refuted is retained. If the results of the analyses indicate compliance, then the process comes to closure and the site is deemed acceptable. If the results do not indicate compliance, then sensitivity analyses (component 7) are conducted to determine the most important (uncertain and lead to noncompliance) parameters and assumptions. Based on the results of the sensitivity analyses, new data collection activities are defined to reduce uncertainty and defensibly relax conservatism. The second decision point in the process is where data-worth (component 8) questions are asked. It requires that the necessary data be attainable for the process to continue. If the data cannot be attained, then a defensible basis does not exist to refute the conservative assumptions we want to relax. If the data can be collected, then the assumptions and parameters are updated using the new data and the process is repeated.

There are several advantages to using an iterative approach to performance assessment. Firstly, the iterative approach requires explicit consideration of the ultimate goal of a performance assessment. That goal is to make a regulatory decision about site safety. Since performance assessment modeling occurs early in the process, all requisites for that modeling effort need to be in place. A performance measure of site safety must be derived from the applicable regulations. Next, an explicit conceptual model of the system along with an associated mathematical modeling approach must be developed for the purpose of comparing simulations of site performance against the performance measure. And lastly, data requirements are dictated by the input requirements of the mathematical models. Because performance assessment modeling occurs early on, an explicit link to regulatory decision making also occurs early on. The iterative approach to performance assessment mandates "back to front" thinking in which the regulations prescribe the performance measure, the performance measure guides decisions about the conceptual model and mathematical models, which in turn specify the initial data and parameter needs. Without an iterative approach, conceptualization of the system to be modeled can be vague. If performance assessment modeling is preceded by the site characterization process, the conceptual model of how the system operates need not be stated in anything more than general terms and it need not be linked explicitly to a performance measure derived from the regulations. Consequently, data and parameter needs cannot help but be somewhat ambiguous.

Secondly, the results of an initial performance assessment along with an accompanying sensitivity analysis can be used to guide data collection. Sensitivity analysis identifies the parameters having the greatest influence on the model results. This information can then be used to guide data collection. This notion is straightforward in theory, if not always in practice. Also, since an unambiguous conceptual model must be constructed early on for modeling purposes, it can serve as a lightning rod for review and debate. Uncertainties in the conceptual model that become highlighted in the course of such debate can sometimes be tested through additional data collection or experimentation. Again, without an iterative approach, we must rely solely on the intuition and experience of the investigators for setting data collection priorities. While this may be acceptable for simple problems, it frequently leads to collection of either insufficient or extraneous data for performance assessments of more complex systems.

Thirdly, the iterative approach facilitates troubleshooting. Problems are identified relatively quickly because all steps of the performance assessment process have been executed once by completion of the first iteration. This "once through quickly" helps to reveal inadequacies of the performance assessment. Solutions to the problems identified can then be implemented in a timely fashion. In many instances, the exercise of having completed all the steps required in a performance assessment iteration can be just as important as the results obtained from that iteration.

We maintain that by using the approach just described, simplistic models of radionuclide migration may be sufficient to make decisions about site performance. Our goal is not to understand the system completely, but instead to incorporate only those processes that could potentially affect the regulatory decision to be made. In the process, conservative assumptions are invoked where we are uncertain, where the modeling approach can be simplified and made more defensible, or where the amount of site characterization data needed to be collected can be reduced. We do this because our objective is to provide the analysis in support of making a regulatory decision as quickly and cost effectively as possible.

IV. PERFORMANCE ASSESSMENT OF THE GCD SITE

The GCD site has provided a real-site implementation of the Sandia performance assessment methodology. Price *et al.*[6,16,17] has documented the preliminary performance assessment (PPA), the first iteration in the GCD facility performance assessment. Based upon extant site information, we made our first assessment of the potential release pathways. This first performance assessment iteration also allowed us to develop conceptual models to describe these pathways and expressed these conceptual models as computer simulations. The primary pathways included a downward advective transport pathway and an upward diffusive pathway. Probabilistic computer simulations of the site were conducted. For the majority of the simulations the transport was dominated by the advective pathway. Results suggested that compliance was reasonably assured for the case of current climatic conditions continuing. That is, in spite of the fact that the CCDF slightly exceeds the EPA limit, we believe that because of the exceedingly conservative nature of the conceptual models used, the GCD was likely to show compliance under existing conditions. The CCDF representing the site under existing conditions is shown in Figure 5. However, this was not the case for a very conservative climate change conceptual model that the PPA also considered. That is, under very much wetter conditions for the entire 10,000 year performance period, the calculated releases exceeded the limits specified in the EPA requirements. Because of the location of the base-case CCDF on the plot and the results of the climate change scenario, it was decided that additional site data were needed. These important data needs were subsequently identified through a sensitivity analysis.

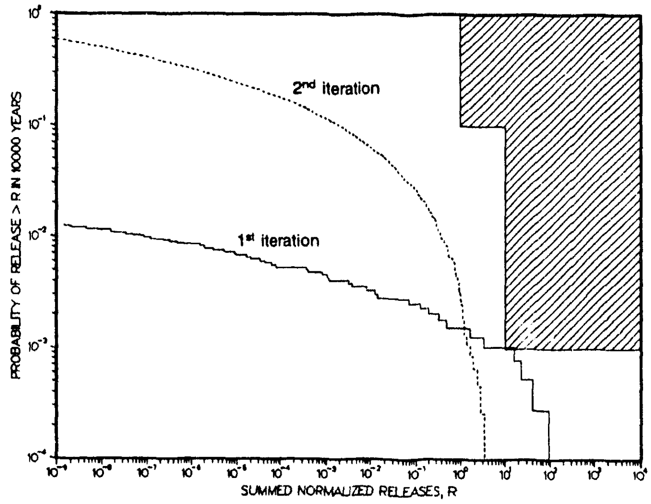

Figure 5. Base Case CCDFs for First and Second Iterations of GCD Performance Assessment

Rate of downward recharge was the most important parameter identified by the PPA's sensitivity analysis for further characterization. As a result, an investigation was conducted by Sandia, the Desert Research Institute, and Reynolds Electrical and Engineering Co. to reduce the uncertainty in this parameter. In this investigation, measurements of depth profiles of environmental tracer species (identifiable species always present in natural systems) was the method determined to be most applicable for estimating recharge within the very dry NTS environment. The inferences that can be drawn from the field data are described in Conrad.[18] For purposes of performance assessment, the most relevant conclusion was that there was substantial evidence that under current climatic conditions the rate of downward recharge is so small that it is not possible for the GCD site to communicate with the unconfined aquifer below it in a period of 10,000 years, the compliance period established by 40 CFR 191.

This conclusion eliminated downward advection to the water table and subsequent transport in groundwater flow as an escape pathway. The only other release pathway available to the majority of the contaminant radionuclides was via diffusion upwards in the vadose zone water and release to the accessible environment by either direct release at the surface or indirect release after being absorbed into plant roots. Consequently, erosion would also have to be evaluated as a possible mechanism that may decrease the effective depth to waste, and may therefore facilitate higher releases. Gas phase releases (specifically radon) will also be evaluated; however, because radon release is not regulated by 40 CFR 191, it is not discussed further here.

Incorporating this new site information, especially the facts concerning recharge, became the focus of the second GCD performance assessment iteration, which is documented in Baer *et al.*[19] The new release conceptual model centered around a simple one-dimensional upward diffusion model. The modelling of plant uptake was also a major feature of this iteration since this pathway has considerably more importance than it did under the PPA's conceptual model. In addition, a simple model of erosion was included in this iteration. The primary conclusion reached, as in the PPA, was that for current climatic conditions continuing the GCD site was shown to comply with the regulations. The CCDF showing the results for the second performance assessment iteration is also shown in Figure 5. In the CCDF for the second iteration, there are a higher number of high-probability, low-release simulations than in the first because, in the latter iteration the diffusion pathway was the only one modeled. In the first iteration, although the diffusive pathway was relatively important compared to the advective pathway, only a few Monte Carlo vectors resulted in diffusion dominated transport. In addition, because of the larger uncertainties and pathways and parameters used in first iteration, the results were more variable. The sensitivity analysis for the second performance assessment identified the tortuosity parameter as having the overwhelming role in controlling the release from the disposed contaminants. This parameter is essentially a factor that reduces the molecular diffusion parameter in order to account for the slowed diffusion rates resulting from the porous medium.

Note that the second performance assessment was not a complete performance assessment as required by 40 CFR 191. The effects of disruptive events and processes, most notably a change in climate, were not addressed in this iteration. The primary focus of the subsequent third iteration will be to incorporate the consequences and probabilities of these disruptive processes.

Third Performance Assessment Iteration of GCD. A complete performance assessment must include the effects of a change in climate, since it is virtually certain that the climate at NTS will change at some point within the next 10,000 years. The changes in temperature and precipitation rates that are likely to be encountered under a change in climate are under current scrutiny, and the effects these might have on infiltration/recharge rates, erosional processes, and plant and animal communities are also being considered. Temperature and precipitation rates may be inferred from measurements of Searles lake sediment, a paleo-lake located in southeastern California. Changes in plant and animal communities will be inferred from the temperature and precipitation rates by reference to analog sites and data collection. The results of these climate change studies will be one aspect of the third performance assessment analyses.

Neither the PPA nor the second performance assessment iteration completely considered all features, events and processes that could disrupt the site. Such an analysis is required by 40 CFR 191. After a detailed screening processes, several such events have been identified including, subsidence/caving of the alluvium above the boreholes, intrusion into the boreholes as a result of exploratory drilling for natural resources including water, and changes in land use that would lead to irrigated farming over the GCD site. Release models for these events will be proposed and contaminant release levels computed. Estimation of probabilities will necessarily be a part of the analysis.

V. SUMMARY

A robust performance assessment methodology has been proposed and applied to the analysis of the Greater Confinement Disposal facility located at the Nevada Test Site. The performance assessment is currently in its third iteration for this site. The methodology integrates regulatory and physical information to focus the development of conceptual models, to guide the collection of site characterization data, to provide a mechanism for making defensible regulatory decisions, and to provide closure of the compliance assessment process.

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