Conf-9110168--2

SAND91-0913C

NEED TO USE PROBABILISTIC RISK APPROACH IN PERFORMANCE ASSESSMENT OF WASTE DISPOSAL FACILITIES [a,b]

Evaristo J. Bonano and David P. Gallegos
Sandia National Laboratories
Albuquerque, NM 87185

SAND--91-0913C

DE92 000234

ABSTRACT

Regulations governing the disposal of radioactive, hazardous, and/or mixed wastes will likely require, either directly or indirectly, that the performance of disposal facilities be assessed quantitatively. Such analyses, commonly called "performance assessments," rely on the use of predictive models to arrive at a quantitative estimate of the potential impact of disposal on the environment and the safety and health of the public. It has been recognized that a suite of uncertainties affect the results of a performance assessment. These uncertainties are conventionally categorized as (1) uncertainty in the future state of the disposal system (facility and surrounding medium), (2) uncertainty in models (including conceptual models, mathematical models, and computer codes), and (3) uncertainty in data and parameters. Decisions regarding the suitability of a waste disposal facility must be made in light of these uncertainties. Hence, an approach is needed that would allow the explicit consideration of these uncertainties so that their impact on the estimated consequences of disposal can be evaluated. While most regulations for waste disposal do not prescribe the consideration of uncertainties, it is proposed that, even in such cases, a meaningful decision regarding the suitability of a waste disposal facility cannot be made without considering the impact of the attendant uncertainties. A probabilistic risk assessment (PRA) approach provides the formalism for considering the uncertainties and the technical basis that the decision makers can use in discharging their duties. A PRA methodology developed and demonstrated for the disposal of high-level radioactive waste provides a general framework for assessing the disposal of all types of wastes (radioactive, hazardous, and mixed).

INTRODUCTION

To demonstrate that the disposal of radioactive, hazardous, or mixed wastes does not pose a significant risk to the health and safety of the public and the environment, the performance of waste disposal facilities must be ascertained to establish that these can effectively isolate the wastes. Typically, this requires an analysis that includes both quantitative and qualitative components. This analysis provides the basis for deciding whether or not the waste disposal presents a significant risk by comparing the results of the analysis to some regulatory criterion.

---

[a] This work performed at Sandia National Laboratories which is operated for the U.S. Department of Energy by Sandia Corporation under Contract No. DE-AC04-76DP00789.

[b] Presented at the 7th Annual DOE Model Conference on Waste Management and Environmental Restoration; Oak Ridge, TN, October 14-17, 1991.

Wastes are conventionally disposed of by burying them underground. Such burial varies from an accidental spill to shallow-land burial to deep disposal in geologic repositories. Whatever the case may be, the nature of the disposal systems (engineered facility and surrounding geologic medium) is such that the quantitative analysis -- conventionally known as a performance assessment -- cannot be conducted with one hundred percent certainty.

Uncertainties will have an impact on the result of calculations performed to predict the fate of contaminants buried in the disposal facilities. The contaminants can be transported from the waste disposal facility through the geosphere to a location where they become accessible to humans and, hence, could be hazardous to the health and safety of the public and/or to the environment. The purpose of a performance assessment is to determine the risk associated with the disposal, planned or accidental, of wastes.[1] The performance assessment evaluates one or more quantities -- known as performance measures -- the value of which are compared to the applicable regulatory requirements. Because of the inherent uncertainties, it cannot be expected that a performance assessment will yield a single deterministic value for the performance measure(s) of choice.

Therefore, it is imperative that uncertainties be dealt with in an explicit manner when estimating the impacts of the waste that has been disposed. Decisions regarding the suitability of waste disposal facilities must be made with a clear understanding of the impact of the uncertainties.[2,3] It is only in this manner that regulatory decisions can be made with any degree of robustness and, hence, can be defended.[2]

An integral part of a performance assessment is uncertainty analysis. This uncertainty analysis considers all potentially significant sources of uncertainty in a formal and explicit manner and attempts to quantify the uncertainties and propagate their impact to the results of the performance assessment.

In this paper, we discuss the different types of uncertainty that can affect the results of a performance assessment, approaches for treatment (identification, quantification, reduction, and propagation) of the uncertainties, and methods for representing the uncertainties. Finally, we advocate the use of a probabilistic risk assessment (PRA) approach for considering the uncertainties.

TYPES OF UNCERTAINTY

There are three basic types of uncertainty typically considered in a performance assessment. These are:[4,5] (1) uncertainty in the future state of the disposal system, (2) uncertainty in the models used, and (3) uncertainty in the parameters required by the models. While it is difficult to ascertain where one type of uncertainty ends and another begins, classifying the types of uncertainty in this manner facilitates dealing with them. Below, we summarize these types of uncertainty; for more detailed discussions on the subject, the reader is referred elsewhere.[4,5]

In reality, there can be only one possible temporal evolution of the disposal system. However, our inability to predict this evolution does not permit us to predict the future state that the disposal system can attain over the length of the prescribed regulatory period, which can range from hundreds or thousands of years to no time limit. Thus, there is uncertainty associated with the future state of the disposal system. Although it is recognized that other time-related uncertainties (specifically, uncertainty in the past and present states of the system) exist, these are generally accounted for under model or parameter uncertainty.

Models are simplifications of a real system regardless of their level of complexity. Hence, uncertainty is inherent in every model. Uncertainty in models conventionally used in performance assessment can be further classified into three types; (1) conceptual model uncertainty, (2) mathematical model uncertainty, and (3) computer code uncertainty.

A conceptual model includes the processes assumed to be occurring in the system, the parameters selected to represent these process (including initial and boundary conditions), and the spatial and temporal scales over which these processes occur. Development of conceptual models is based on simplifications regarding the geometry and dimensionality of the system, initial and boundary conditions, material properties, and nature of the attendant physicochemical processes. The uncertainty in conceptual models arises from our inability to establish with a reasonable degree of certainty the validity of the simplifications made given the intended use of the model.

Once a conceptual model has been formulated, it must be represented using mathematical expressions (i.e., a mathematical model). The uncertainty in mathematical models results from approximations made so that the attendant processes can be represented with tractable mathematical equations. A solution of the equations using available analytical and/or numerical solutions can then be determined.

Frequently, the mathematical models needed in performance assessment analyses are too complex to allow simple solutions. Thus, their solutions are often implemented using computer codes. The use of codes introduces uncertainties resulting from possible coding errors, computational limitations, and user errors.

Finally, to obtain a numerical value of the performance measure(s) of interest in a performance assessment, the models and the associated computer codes must be executed. This execution requires that the parameters in the models be assigned numerical values. The parameters themselves are not measured directly but rather are inferred indirectly from measured data. These measured data are uncertain because of limited accuracy and precision of measuring instruments, inability to characterize spatial variability, and human error. Uncertainty in parameters incorporates the data uncertainty plus uncertainty introduced in data interpretation and reduction.

TREATMENT OF UNCERTAINTY

The treatment of uncertainty in performance assessment generally includes four steps; these are the identification, quantification, reduction, and propagation of uncertainty. To achieve reasonable assurance that the assessment of a site is complete, a goal of performance assessment is to apply, either implicitly or explicitly, all of these steps to each type of uncertainty identified above.

Identifying sources of uncertainty, often conducted implicitly, is basically the process of making assumptions about the characteristics and behavior of the site. As a result, identifying the sources of uncertainty is often qualitative. Uncertainty arises because knowledge of the system (past, present and future) is not complete and, consequently, the assumptions made about the system can be inaccurate or the list of important assumptions and their relationships may be incomplete. Identification of uncertainty, as described here, is implicitly part of "types" of uncertainty, but goes beyond the latter by recognizing specific assumptions.

As mentioned earlier, a quantitative representation of the predicted behavior of the disposal site is provided through the results of predictive models. During the initial stages of the performance assessment, scenarios are developed to represent the uncertainty associated with the future state of the system. Likewise, alternative conceptual models represent uncertainty associated with the characteristics of the site and the attendant processes. In addition to its inherent relationship to uncertainty in models, parameter uncertainty is further complicated by natural variability. The uncertainty and variability in parameters is often represented quantitatively by probability density functions. Uncertainty is incorporated in the estimates of the regulatory performance measure by quantification and propagation of the uncertainty through the system models. The uncertainty associated with the scenarios, models and parameter values is further revised and possibly reduced during subsequent iterations of the performance assessment process, as more information becomes available and/or more knowledge is gained.

Some of the techniques used and/or proposed for the treatment of uncertainty are summarized in Table 1. Note that identification of uncertainty occurs as part of the first two columns in Table 1. The reader is referred elsewhere for further discussion of the treatment of uncertainty in performance assessment.[4,5,6,7,8]

REPRESENTATION OF UNCERTAINTY

The method for representing the uncertainty in the prediction of site performance is closely related to, or dictated by, the applicable regulations for a given site and also is closely tied to the purpose of the assessment. There are essentially two ways to represent the quantitative, predicted values of the site performance measures; these are bounding (or conservative) estimates and probabilistic-distribution representation. The latter is a direct result of uncertainty analysis, whereas the former may or may not involve explicit uncertainty analysis.

Table 1. Sources and Treatment of Uncertainty

Type of Uncertainty	Identification / Reduction	Quantification / Propagation
Future State of the System	Development of Scenarios	Scenario Probabilities
Models and Codes (i.e., Conceptual, Mathematical, and Numerical Models)	Development of Conceptual Models Verification and Benchmarking Validation	Alternative Conceptual Models Conceptual Model Probabilities
Data and Parameters	Data Collection	Probability Density Functions Monte Carlo Simulations

Bounding (i.e., conservative) calculations can provide a deterministic, limiting estimate of the site behavior. The estimates can be useful if they are based on a clearly conservative set of parameter values and models. However, it is often difficult to predict *a priori* which combination of parameter values will ultimately result in the most conservative estimate. Consequently, numerous combinations of parameters might have to be analyzed to discover which combination results in the most conservative estimate. Additionally, a single conservative result cannot convey the degree of confidence that the modeler has in the predictions.

A probabilistic distribution representation, on the other hand, explicitly displays the uncertainty associated with the predictions. This provides the regulatory decision maker with a degree of confidence that a given site demonstrates compliance with the applicable regulations, be they deterministic or probabilistic. Furthermore, through quantification and propagation of uncertainty, valuable information can be gained as to which models, scenarios, and parameters contribute to the uncertainty associated with the performance measure.

ROLE OF PROBABILISTIC APPROACH IN ADDRESSING REGULATIONS

As mentioned above, an important aspect of performance assessment is an uncertainty analysis that allows for the formal and explicit consideration of uncertainties. Furthermore, to the extent practicable, the uncertainties should be quantified and propagated to the results of the performance assessment. Of course, it is understood that every practical attempt should be made to reduce those uncertainties that are expected to have the largest effect on the results of the performance assessment and, consequently, on the decision making process.

Uncertainties are quantified using probabilities. "Probability," as used in this paper, means degree of belief.[9] While there are different approaches for quantifying probabilities with different degrees of complexity, the Bayesian approach is frequently used because it provides a framework for rigorously and formally quantifying probabilities. A probabilistic framework based on the Bayesian or Subjectivistic Probability Theory allows the incorporation of all sources of information in the quantification of probabilities, particularly the use of expert judgments.[1,9] The use of Bayesian Theory yields subjective probabilities that assign weights to scenarios, models, and parameter values.

Once the important uncertainties have been quantified, their effect must be propagated in a systematic fashion. Performance assessment methodologies have been developed for the propagation of uncertainty. One such performance assessment methodology has been developed at Sandia National Laboratories to support the U.S. Nuclear Regulatory Commission's high-level radioactive waste (HLW) program.[10,11,12] This methodology was developed to assist in assessing compliance of an HLW repository with the U.S. Environmental Protection regulation for disposal of HLW, spent fuel, and transuranic waste.[3] This regulation is the only one known in the U.S. to contain a requirement that is probabilistic in nature and, therefore, provides the necessary framework for the consideration of uncertainties in an explicit and formal manner.[3,11,13,14]

While, at present, no other regulation is known to prescribe explicitly the consideration of uncertainty, it has been recognized that the type of regulatory decisions that need to be made regarding waste disposal necessitate accounting for the impact of uncertainties. For this reason, the HLW performance assessment methodology aforementioned has provided the basis for the development of a more generic methodology applicable to waste disposal in general;[15] this methodology --known as "probabilistic risk assessment methodology" -- is shown schematically in Figure 1. This probabilistic risk assessment methodology relates the effect of uncertainties to the estimation of risk, which is defined as the product of consequence and probability.

As shown in Figure 1, the estimate of total risk has two components: (1) risk from dose and health effects resulting from releases of those waste constituents that present a hazard and (2) economic risk associated with such releases. Dividing risk into these two components allows the decision maker to evaluate all available information that will impact the decision and, hence, allow for thorough scrutiny and defensibility of the decision. An example of the latter is the development of a "Below Regulatory Concern" (BRC) policy. Commonly, BRC is equated with the concept of a *deminimus* level. However, while the two are related they are not synonymous to each other. A *deminimus* level is based on health risk whereas BRC considers the health risk as well as other factors such as economic ones. In this case, it is reasonable to expect that a BRC risk level will be somewhat higher than a *deminimus* risk level.

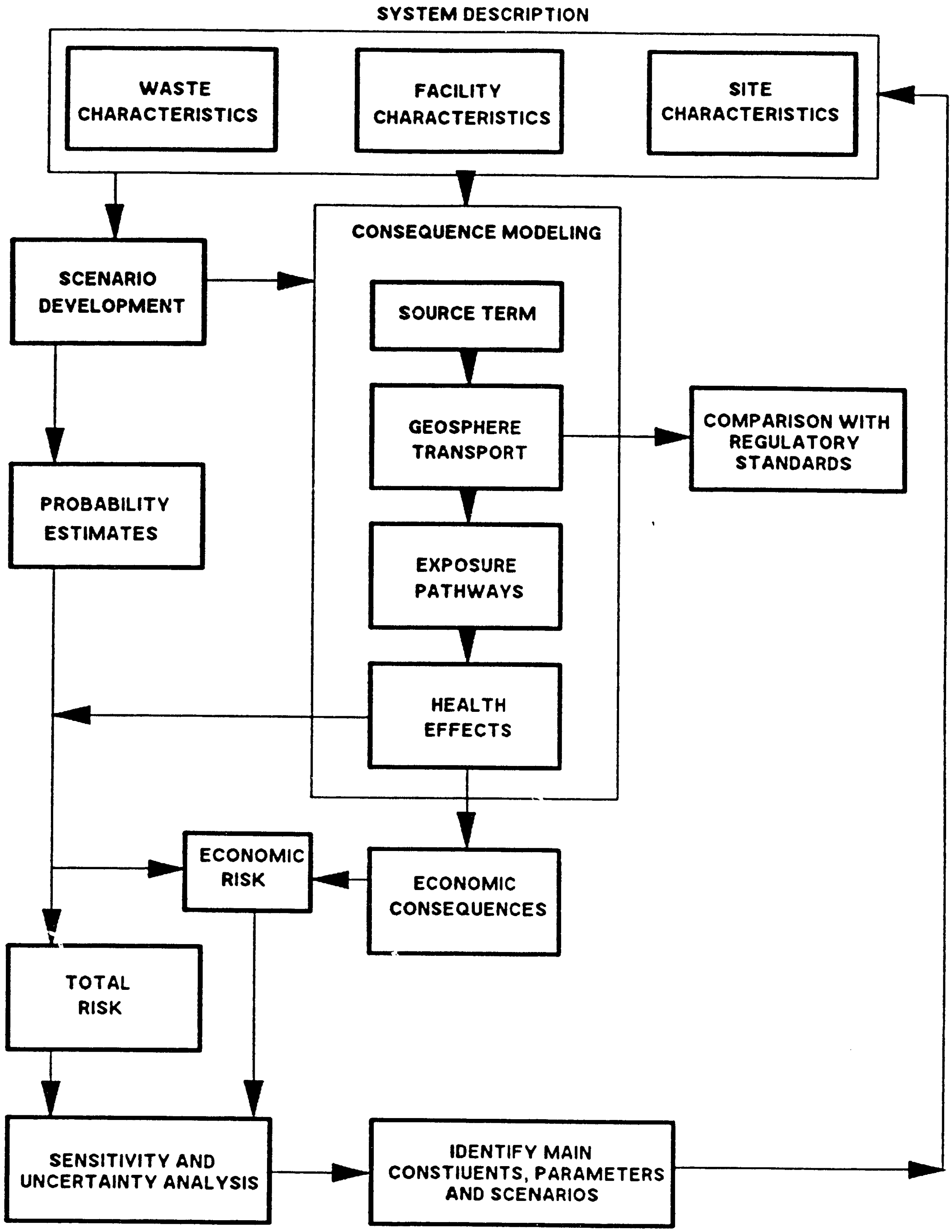

Figure 1. Probabilistic Risk Assessment Methodology

SUMMARY AND CONCLUSIONS

Because of the predictive nature of waste disposal performance assessment, and the spatial and temporal scales over which those predictions are generally made, uncertainty associated with the characteristics and behavior the disposal system is an issue that must be dealt with. This paper has discussed the types of uncertainty that can affect the results of a performance assessment, the treatment of uncertainty, and the representation of uncertainty in the performance assessment analysis and in the performance measure. Because it is necessary to represent the inherent uncertainty involved in model predictions, we advocate the use of a probabilistic risk approach to performance assessment. Such an approach provides a framework that would allow the consideration of uncertainties in an explicit manner so that their impact on the estimated consequences of disposal could be evaluated, regardless of whether the regulatory performance measure is deterministic or probabilistic.

REFERENCES

1. Bonano, E. J. and G. E. Apostolakis, "Theoretical Foundations and Practical Issues for Using Expert Judgments in Uncertainty Analysis of High-Level Radioactive Waste Disposal," in press, Radioactive Waste Management & the Nuclear Fuel Cycle.

2. Finkle, A. M., Confronting Uncertainty in Risk Management: A Guide for Decision-Makers, Center for Risk Management Resources for the Future, Washington, DC, 1990.

3. 40 CFR Part 191, Environmental Standard for the Management and Disposal of Spent Fuel, High-Level Waste and Transuranic Waste, Working Draft 3, U.S. Environmental Protection Agency, Washington, DC, 1991.

4. Bonano, E. J. and R. M. Cranwell, "Treatment of Uncertainties in the Performance Assessment of Geologic High-Level Radioactive Waste Repositories," Mathematical Geology, 20:(5), 1988.

5. Davis, P. A., E. J. Bonano, K. K. Wahi, and L. L. Price, Uncertainties Associated with Performance Assessment of High-Level Radioactive Waste Repositories, NUREG/CR-5211, U.S. Nuclear Regulatory Commission, Washington, DC, and SAND88-2703, Sandia National Laboratories, Albuquerque, NM, 1990.

6. Zimmerman, D. A., K. K. Wahi, A. L. Gutjahr, and P. A. Davis, A Review of Techniques for Propagating Data and Parameter Uncertainty in High-Level Radioactive Waste Repository Performance Assessment Models, NUREG/CR-5393, U.S. Nuclear Regulatory Commission, NUREG/CR-5393, Washington, DC, and SAND89-1432, Sandia National Laboratories, SAND89-1432, Albuquerque, NM, 1990.

7. Helton, J. C., J. W. Garner, R. D. McCurley, and D. K. Rudeen, Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant, SAND90-7103, Sandia National Laboratories, Albuquerque, NM, 1991.

8. Davis, P. A., and N. E. Olague, "Treatment of Modeling Uncertainties in Total System Safety Assessments," proceedings of the International Conference on Probabilistic Safety Assessment and Management (PSAM), Feb. 4-7, 1991, Beverly Hills, CA, G. E. Apostolakis, ed., 1991.

9. Chhiber, S., G. Apostolakis, and D. Okrent, "A Probabilistic Framework for the Analysis of Model Uncertainty," Trans. IChemE, 69, Part B, 1991.

10. Bonano, E. J., R. M. Cranwell, and P. A. Davis, "Performance Assessment Methodologies for the Analysis of High-Level Nuclear Waste Repositories," Radioactive Waste and the Nuclear Fuel Cycle, 13, 1989.

11. Bonano, E. J. and K. K. Wahi, Use of Performance Assessment in Assessing Compliance with the Containment Requirements in 40 CFR Part 191, NUREG/CR-5521, U.S. Nuclear Regulatory Commission, Washington, DC, and SAND90-0127, Sandia National Laboratories, Albuquerque, NM, 1990.

12. Gallegos, D. P., A Performance Assessment Methodology for High-Level Radioactive Waste Disposal in Unsaturated, Fractured Tuff, NUREG/CR-5701, U.S. Nuclear Regulatory Commission, Washington, DC, and SAND91-0539, Sandia National Laboratories, Albuquerque, NM, 1991.

13. Cranwell, R. M., J. E. Campbell, J. C. Helton, R. L. Iman, D. E. Longsine, N. R. Ortiz, G. E. Runkel, and M. J. Shortencarier, Risk Methodology for Geologic Disposal of Radioactive Waste: Final Report, NUREG/CR-2452, U.S. Nuclear Regulatory Commission, Washington, DC, and SAND81-2573, Sandia National Laboratories, Albuquerque, NM, 1987.

14. Bonano, E. J., P. A. Davis, L. R. Shipers, K. F. Brinster, W. E. Beyeler, C. D. Updegraff, E. R. Shepherd, L. M. Tilton, and K. K. Wahi, Demonstration of a Performance Assessment Methodology for High-Level Waste Disposal in Basalt Formations, NUREG/CR-4759, U.S. Nuclear Regulatory Commission, Washington, DC, and SAND86-2325, Sandia National Laboratories, Albuquerque, NM, 1989.

15. Rechard, R.P., M. S. Y. Chu, and S. L. Brown, SRS: Site Ranking System for Hazardous Chemical and Radioactive Waste, SAND86-2994, Sandia National Laboratories, Albuquerque, NM, 1988.

END

DATE FILMED

10/30/91

II