A PERSPECTIVE ON DEMONSTRATIONS OF COMPLIANCE FOR HIGH-LEVEL WASTE DISPOSAL*

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ABSTRACT

This paper discusses a perspective which we have developed on the problem of demonstrating compliance of high-level waste repositories with system performance standards. Our viewpoint arises primarily from two concerns – first, that the U.S. Environmental Protection Agency's proposed environmental standard for high-level waste disposal appears to require demonstrations of compliance which are incompatible with scientific knowledge, and, second, that the federal agencies involved in the licensing process may not appreciate fully the extent of unquantifiable and unresolvable uncertainty in repository performance-assessment models. We propose a general approach to demonstrations of compliance which we feel is compatible with the kinds of technical information that will be available for judging repository performance. Our approach emphasizes the importance of investigating alternative conceptual models and lines of reasoning in evaluating repository performance and the importance of subjective scientific judgment in the decision-making process.

INTRODUCTION

The process of licensing geologic repositories for the disposal of high-level radioactive wastes will provide a considerable challenge for the U.S. Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), and Department of Energy (DOE). The challenge arises from the fact that demonstrations of compliance of repositories with system performance standards must rely to an unprecedented extent on models of various kinds, but the validity of many of the models for predicting long-term repository performance will be difficult or impossible to establish. Thus, it will be necessary to develop methods of demonstrating compliance which allow decisions on repository safety to be made in spite of significant but irreducible uncertainties in model predictions.

This paper discusses a perspective which we have developed on the problem of demonstrating compliance of high-level waste repositories with performance standards. This perspective has been developed as a result of assessments which we have performed for the NRC on uncertainties in predicting long-term repository performance [1-7].

In presenting our point of view, we first consider the EPA's proposed environmental radiation standard for high-level waste disposal (40 CFR 191) [8]. It is our view that the EPA standard prescribes a relatively inflexible approach to demonstrations of compliance which is incompatible with the kinds of technical information that will be available for licensing decisions. We then discuss the approach to licensing decisions that has been presented by the NRC in its high-level waste standard (10 CFR 60) [9], its analysis [10] of DOE's site characterization work at the Basalt Waste Isolation Project (BWIP) [11], and its position papers on hydrologic and geochemical issues of importance to site characterization and predictions of repository performance [12,13]. We believe that the NRC's approach to demonstrations of compliance contrasts favorably with that indicated by the EPA standard, both in the flexibility of the requirements in 10 CFR 60 and in the NRC's recognition of the limitations of model predictions. However, we also believe that the NRC may be overly optimistic with regard to the extent to which important technical issues can be resolved unambiguously. Finally, we present a general approach to demonstrations of compliance which we believe is compatible with the kinds of technical information that will be available to the NRC in licensing waste repositories. Our approach emphasizes the need to investigate alternative conceptual models and lines of reasoning in evaluating repository performance and the importance of subjective scientific judgment in the decision-making process.

INFLUENCE OF EPA STANDARD ON DEMONSTRATIONS OF COMPLIANCE

As a prelude to discussing the influence of the proposed EPA standard [8] on demonstrations of compliance, we would note that the standard embodies three general principles which we believe are quite sound. First, the standard establishes a level of acceptable risk to the general public which is much less than the acceptable risk for other nuclear

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fuel-cycle activities [14]. We believe that a conservative standard is appropriate for high-level waste disposal because of the necessity of relying on highly uncertain models for predicting long-term repository performance and the impracticality of taking effective remedial actions. Second, the standard requires the use of multiple engineered and natural barriers for waste isolation as a means of reducing the consequences of unexpected failures of one or more parts of the repository system. Third, the way in which acceptable risk is expressed in Table 2 of Subpart B of the standard [8] will focus the licensing process on issues related to the performance of the repository system at specific sites, and not on the more generic issues involving radionuclide pathways to man, dosimetry, and health risk factors.

We are concerned, however, about the implications of the EPA standard for acceptable demonstrations of compliance. The standard defines acceptable repository performance in terms of allowable cumulative releases of radionuclides to the accessible environment over 10,000 years for both "reasonably foreseeable" and "very unlikely" releases. The two categories of releases are defined as those having a probability of occurrence over 10,000 years of greater than 0.01 or a probability between 0.01 and 0.0001, respectively, and the cumulative release limits for very unlikely releases are ten times greater than the limits for reasonably foreseeable releases. The standard also calls for "realistic" projections of repository performance in determining compliance with the release limits. Thus, the EPA standard appears to require probabilistic analyses of repository performance in order to construct a Complementary Cumulative Distribution Function (CCDF) for radionuclide releases which can be compared with the release limits. A CCDF gives the predicted probability that releases to the accessible environment will exceed a given value, and it takes into account quantifiable uncertainties in the probabilities of disruptive events and processes and in the releases that are predicted to result from the disruptive phenomena. Two hypothetical CCDFs for repository performance are shown in Figure 1. The x-axis gives the ratio of predicted releases to the release limits in the EPA standard, and the shaded region indicates releases that would be in violation of the standard.

We believe that the apparent need to construct realistic CCDFs of repository performance in order to demonstrate compliance with the EPA standard leads to several problems.

1. It will not be possible to quantify some uncertainties that arise from the natural variability in geologic systems or that are associated with estimates of probabilities of future geologic processes and events. Geologic data on particular sites will be unavoidably sparse, so that it will be difficult to quantify accurately the extent of variability in geologic properties that are important for hydrologic, geochemical, and thermo-mechanical modeling. Estimates of rates of geologic processes acting at a given site are based largely on skilled judgments and interpretations of available data. Multiple interpretations of the geologic record tend to be the rule rather than the exception, and the interpretations may even be irreconcilable (e.g., see refs. [15] and [16]). Thus, quantitative estimates of rates of geologic processes and probabilities of future disruptive events will be difficult to defend.

2. Even if unquantifiable uncertainties in the geologic environment and in geologic processes and events were not important, predictions of repository performance based on mathematical models will be difficult to defend because many of the models cannot be validated. An inability to validate models may result in significant unquantifiable uncertainties in the model predictions.

3. Evaluations of long-term repository performance will need to consider release scenarios involving inadvertent human intrusion, e.g., drilling into the repository or a contaminated aquifer. Estimates of the probabilities of human intrusion can only be regarded as speculative. This has obvious implications for probabilistic analyses of repository performance if human intrusion is regarded as an important release mechanism.

4. Strict interpretation of the EPA standard may lead to an unintended and undesirable differentiation of licensing and safety issues. The need to provide quantitative estimates of probabilities of disruptive processes and events is an example of an issue that would be important for licensing but would have limited relevance for repository safety. In general, one can adequately judge the potential importance of disruptive phenomena on the basis of qualitative analyses of their likelihood of occurrence (e.g., see refs. [17] and [18]). The requirement of realistic performance assessments may also complicate the licensing process without contributing to repository safety, given the difficulties in quantifying repository performance and its uncertainties [1,2,19]. It seems unwise to exclude the use of simplified and conservative screening tools in judging repository performance for licensing purposes.

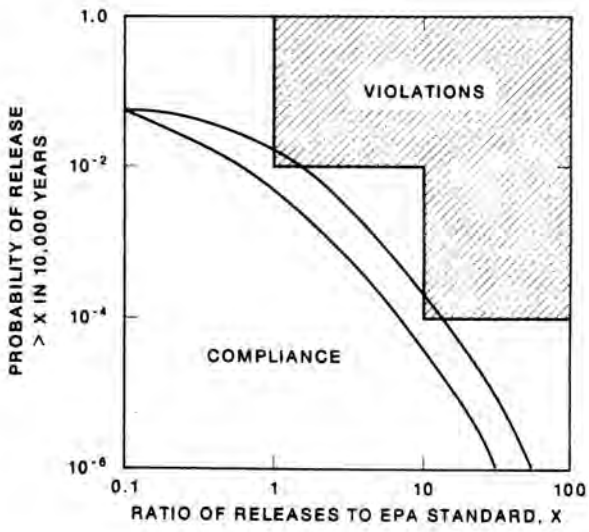

Fig. 1. Hypothetical Complementary Cumulative Distribution Functions for radionuclide releases from a high-level waste repository to the accessible environment over 10,000 years (smooth curves) compared with the limits on cumulative releases in the proposed EPA high-level waste standard (staircase curve) [8]. The region above the staircase curve indicates releases that would be in violation of the standard.

5. The generation of numerical predictions of repository performance using complex mathematical models and associated computer codes tends to create the misleading impression that performance assessment is an objective and quantitative science, and that licensing decisions can be based on complete assurance of acceptable repository performance. It is inevitable that the validity of model predictions will be challenged in the licensing process, and difficulties in defending the models may cause the public to lose confidence in the entire decision-making process.

In summary, the EPA's proposed high-level waste standard [8] appears to prescribe a rather inflexible approach to demonstrations of compliance which is basically incompatible with the kinds of technical information that will be available for judging repository performance. In our interpretation of the EPA standard in Figure 1, the upper of the two hypothetical CCDFs would probably be regarded as indicating a violation of the standard, while the lower curve would represent a repository which is in compliance. In our opinion, however, there would be little to choose between the two repositories on the basis of this information, because the qualitative and subjective aspects of evaluating uncertainties in repository performance are too important for the difference between the two curves to be significant.

NRC PERSPECTIVE ON DEMONSTRATIONS OF COMPLIANCE

The NRC's perspective on acceptable demonstrations of compliance is embodied principally in the Technical Criteria in 10 CFR 60 [9] and in the BWIP Site Characterization Analysis [10]. Important features of the NRC's viewpoint are as follows.

1. Multiple engineered and natural barriers for waste isolation are needed in order to compensate for uncertainties in predicting repository performance and to provide proper assurance that the EPA standard will be met.

2. Qualitative judgments will play an essential role in achieving a finding of "reasonable assurance" that the EPA standard will be met. The concept of "reasonable assurance" has two principal elements. First, performance assessments must indicate a low likelihood of a repository violating the EPA standard, but the needed level of confidence cannot be expressed in quantitative terms. Second, performance assessments must be sufficiently conservative and their limitations sufficiently well understood that actual repository performance will be within predicted limits [9]. Application of this concept to decision making will require an extensive and systematic investigation of a wide range of factors affecting repository performance, and will require DOE to present its case for licensability so that the NRC can perform an independent assessment [20].

3. The 10 CFR 60 rulemaking allows for flexibility in applying the numerical performance objectives for particular engineered barriers and the geologic setting. The NRC will consider both "anticipated" and "unanticipated" processes and events in evaluating repository performance, but the two categories are defined only in qualitative terms because of the difficulty in quantifying probabilities of disruptive phenomena at specific sites.

4. The 10 CFR 60 rulemaking encourages attention to qualitative factors (i.e., the "favorable" and "potentially adverse" conditions) in site selection, and it recognizes the importance of these factors in providing reasonable assurance that the EPA standard will be met.

5. The BWIP Site Characterization Analysis [10] emphasizes the importance of investigating alternative conceptual models in site characterization and in developing performance assessment models.

In our view, the NRC has indicated an appropriate understanding of the difficulties associated with quantitative performance assessments and the essential role of qualitative judgments in demonstrating compliance of a repository with standards. The NRC's perspective contrasts favorably with the relatively inflexible approach to demonstrations of compliance which is indicated by the EPA standard.

We would caution, however, that the NRC's position on acceptable demonstrations of compliance may seem somewhat paradoxical. On the one hand, the NRC has expressed considerable doubt that knowledge of geological sciences is compatible with the construction of realistic CCDFs for repository performance as called for by the EPA standard [9,21]. On the other hand, the NRC clearly expects that a license application will include a CCDF for radionuclide releases to the accessible environment from both anticipated and unanticipated processes and events [9], and the NRC has developed its own risk assessment methodology for generating CCDFs independently [22]. Thus, in our view, the NRC has not yet conveyed a clear impression of the role of calculated CCDFs in reaching licensing decisions.

The NRC is also developing position papers on technical issues of importance to site characterization and performance assessment. These papers provide guidance to DOE on methods for resolving specific issues. Although we believe that the NRC has often conveyed a reasonable understanding of specific issues, we are nonetheless concerned that the NRC has not appreciated fully the extent to which irreducible uncertainties may prevent an unambiguous resolution of the issues. We illustrate this point by discussing two issues which have been addressed by the NRC: (1) hydrologic testing strategies, with particular reference to the BWIP site [10,12], and (2) the determination of geochemical properties of importance to predictions of radionuclide transport in groundwater [10,13].

In the BWIP Site Characterization Analysis [10] and the position paper on hydrologic testing strategy [12], the NRC has recommended reliance on large-scale, multiple-well pump tests for determining hydraulic properties of the host rock, and has suggested that these same tests be used for validating groundwater flow models. Such tests will probably provide valuable information, but we believe that the NRC may have overstated the capabilities of the proposed tests for resolving uncertainties in characterizing the hydrologic system.

The limitations of the proposed hydrologic testing strategy arise from the fact that interpretation of the measurements to obtain estimates of aquifer hydraulic properties is model dependent. The models that are available for this purpose are highly simplified representations of the hydrologic system [23], and the validity of these models cannot be tested without

independent sources of information on system behavior. Both the NRC [10] and DOE [24] have indicated an awareness of problems in interpreting hydraulic data from field tests, but we believe that neither agency has addressed adequately possible ambiguities in results obtained from only one type of hydraulic test.

In our view, the most promising approach to resolving hydrologic issues is to use a variety of methods in site characterization, e.g., multiple-well and single-well testing, observations of geologic structures, and hydrochemical data. Results from several methods, each of which is subject to uncertainty but is based on somewhat different assumptions, should provide a means of limiting the range of possible hydrologic models and parameter values. Thus, this approach should result in less uncertainty than would reliance on a single type of field test.

The NRC's viewpoint on geochemical issues of importance to repository performance assessment is presented in the BWIP Site Characterization Analysis [10] and the position paper on solubility and speciation [13]. The NRC has paid particular attention to oxidation-reduction processes and the solubility of radionuclides in groundwater.

The NRC recognizes the importance of oxidation-reduction (i.e., "redox") processes in determining the mobility of some radionuclides in groundwater. The NRC also conveys an understanding of the limitations of Eh (i.e., the "redox potential") in describing complex geochemical systems. However, it is our impression that even though the Eh concept may not be applicable to these systems and measured values of Eh may not be accurate indicators of the redox potential, the NRC still intends to use the Eh concept in performance assessments. The complexities of oxidation-reduction processes are discussed in more detail elsewhere [5].

The position paper on solubility and speciation [13] mainly emphasizes solubility, probably because this is a parameter that can be used in radionuclide transport modeling. In our opinion, however, the position paper presents a view of solubility and its applicability to performance assessments which is overly simplistic and which contrasts noticeably with the better scientific balance achieved in the BWIP Site Characterization Analysis [10].

The position paper implies that by measuring solubility, the concentrations of ionic species in equilibrium with a well-characterized solid phase can be determined, and that solubility data are adequate for estimating radionuclide concentrations in the far-field zone. However, only the Site Characterization Analysis conveys a proper understanding of (1) the need for thermodynamic data on hydrolysis and complexation reactions in order to determine the speciation of transuranium compounds in near-neutral solutions, (2) the importance of information on the concentrations of particular species and their interactions with the geologic media from the disturbed zone outward in estimating concentrations in the far-field zone, and (3) the potential importance of kinetic effects and the formation of colloids as sources of uncertainty in geochemical modeling.

As with the hydrologic issues discussed above, it is our view that the NRC may not be fully aware of the need for models in interpreting geochemical data and estimating parameters of interest, and that the choice of models may introduce significant unquantifiable uncertainty into the estimates. We believe that the best approach to resolving geochemical issues involves an extensive effort along several lines including laboratory research, field studies, and studies of natural analogs. However, one should not expect that such a program will resolve all issues unambiguously.

A PERSPECTIVE ON DEMONSTRATIONS OF COMPLIANCE

The discussions in this paper have served to illustrate our concern that the extent of unquantifiable and unresolvable uncertainty in demonstrating compliance of high-level waste repositories with the EPA standard [8] may not be properly appreciated by the various federal agencies involved in the licensing process. The potential importance of this type of uncertainty results basically from the use in performance assessments of models that cannot be validated. The way in which the EPA standard is formulated appears to be based on the belief that probabilistic analyses using mathematical models will provide reliable indicators of overall system performance. In contrast to this point of view, the NRC has indicated an appreciation of the limitations of quantitative performance assessments [9,10]. Yet, we are left without a clear impression of how the NRC intends to take these limitations into account in reaching licensing decisions. The DOE's approach to demonstrations of compliance, as presented in the BWIP Site Characterization Report [11], indicates to us a considerable confidence in quantitative performance assessment and in the ability of experiments and field studies to resolve technical issues unambiguously.

We believe that it is important to develop a decision-making process which ensures that safe waste repositories are indeed licensable, even when strict compliance with quantitative performance standards cannot be demonstrated. We believe that in order to be successful, the approach to demonstrations of compliance and licensing decisions should embody the following general principles:

[1] commitment to a comprehensive program of laboratory research, field studies, and data collection coupled with a recognition that significant ambiguities are likely to remain in characterizing aspects of the repository system which are important for waste isolation;

[2] continual development and testing of alternative conceptual models and working hypotheses for site characterization and predictions of repository performance as a means of increasing confidence that the range of possible outcomes has been defined properly;

[3] recognition that probabilistic analyses of repository performance are just one of several tools that must be used in decision making;

[4] recognition that the validity of any experiment or modeling exercise for predicting repository performance is inherently limited by the validity of the particular conditions or assumptions involved;

[5] commitment to the multiple barrier concept as a means of compensating for uncertainties in predicting overall repository performance;

[6] recognition of the potential importance of irreducible residual uncertainties in predicting repository performance;

[7] acceptance of qualitative "weight of evidence" and "reasonable assurance" arguments in evaluating compliance of a repository with quantitative performance standards;

[8] recognition of the essential role in evaluating repository performance of subjective judgments and expert opinions; and

[9] an understanding by the scientific community of the judgmental nature of the decision-making process and communication to the public that some uncertainty will remain when all the evidence is weighed, so that it will not be possible to guarantee waste isolation even though experts may be confident that waste disposal is safe.

We believe that these principles are compatible with the kinds of technical information that will be available when licensing decisions are made. The NRC has clearly recognized the importance of many of these principles in developing its licensing strategy [9,10]. We urge the NRC to continue developing a comprehensive, cautious, and forthright approach to repository licensing, because we believe that such an approach will be required in order to complete the task successfully.

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