PERSPECTIVES ON DEVELOPING INDEPENDENT PERFORMANCE ASSESSMENT CAPABILITY TO SUPPORT REGULATORY REVIEWS OF THE SAFETY CASE

James R. Winterle, Center for Nuclear Waste Regulatory Analyses
Andrew C. Campbell, U.S. Nuclear Regulatory Commission

Abstract

The U.S. Nuclear Regulatory Commission (NRC) has the responsibility under U.S. statutes and regulations to conduct a review of the U.S. Department of Energy (DOE) license application for a potential high-level nuclear waste repository at Yucca Mountain, Nevada, USA. A key component of the DOE license application will be a total system performance assessment to demonstrate compliance with regulatory requirements for postclosure repository performance. The NRC staff, with assistance from the Center for Nuclear Waste Regulatory Analyses (CNWRA), has developed an independent performance assessment review capability that includes applying available risk insights to be able to identify those aspects of the DOE postclosure safety case that are most important to demonstrating regulatory compliance. To advance the development of risk insights, the NRC and CNWRA staffs have developed an independent total system performance assessment model of the potential Yucca Mountain repository. This paper provides an overview of perspectives gained from the development and iterative improvement of independent total system performance assessment capabilities and how those capabilities will aid in the regulatory review of the DOE performance assessment.

Introduction

The United States is considering the Yucca Mountain site in southern Nevada as the location for a geologic repository for disposal of high-level radioactive wastes. The DOE is charged with the tasks of site characterization, repository design, and development of a license application to demonstrate that the potential repository will meet regulatory requirements specified in Part 63 of Title 10 of the Code of Federal Regulations (10 CFR Part 63). DOE is presently preparing its license application for a geologic repository at the Yucca Mountain site. The U.S. regulations require that reasonable expectation of safety be demonstrated in the license application for postclosure performance. Moreover, the U.S. approach envisions a safety case will be documented in the license application. Thus, in this paper, the use of the term safety case should be considered synonymous with the license application. The NRC will review a DOE license application to ensure the regulatory requirements of 10 CFR Part 63 are met. The DOE has stated that, in June 2008, it will submit a license application for NRC review. Under the Nuclear Waste Policy Act of 1982 as amended, the NRC has three years to issue a final decision approving or disapproving the issuance of a construction authorization. That decision will not be made until the NRC completes its review process, including an acceptance review, a safety evaluation, and adjudicatory hearings. During the time period prior to receiving the license application (the "prelicensing period"), the NRC staff is reviewing the DOE site characterization activities and investigations to help identify potential licensing issues and prepare the NRC to conduct its review.

A key part of the DOE safety case (i.e., DOE license application) will be a total system performance assessment (TSPA) to demonstrate compliance with regulatory postclosure performance objectives. Because the TSPA is important to the DOE license application, NRC prelicensing

activities have placed high priority on developing an understanding of how site characterization and design information are incorporated into the DOE TSPA model. To that end, the NRC and its technical support organization, the Center for Nuclear Waste Regulatory Analyses (CNWRA), have developed an independent performance assessment review capability that includes application of risk insights to help identify those aspects of the DOE safety case that are important to demonstrating regulatory compliance.

To advance the development of risk insights, the NRC and CNWRA staffs have developed an independent total system performance assessment (TPA) model of the potential Yucca Mountain repository. This independently-developed model provides NRC with a tool for understanding the relative importance of various natural and engineered barrier system and subsystem components without having to wait for, and rely solely on, DOE models and data to develop this understanding. While there are clear benefits to having this independent performance assessment capability, there are also costs in terms of resources and staff time. This paper provides an overview of perspectives gained from the development of independent total system performance assessment capabilities and how those capabilities will aid in the regulatory review of the DOE performance assessment. It is hoped that these perspectives benefit regulators of other national or international high-level waste disposal programs who may be considering developing their own independent performance assessment capabilities.

Purpose of performance assessment

To begin, it is important to understand that license applicants and regulators have decidedly different motivations for developing their TSPA models. In the U.S. program, the DOE, as a potential license applicant, is required by regulation (10 CFR 63.113) to conduct a performance assessment to quantitatively estimate radiological exposures to the reasonably maximally exposed individual at any time during the postclosure compliance period. The performance assessment also is appropriate for demonstrating compliance with performance objectives for groundwater protection and human intrusion and for providing the required demonstration of multiple barriers. Specific requirements (10 CFR 63.114) are that the applicant's performance assessment must (i) include data related to the natural and engineered barrier systems used to define parameters and conceptual models; (ii) account for uncertainty and variability in parameter values; (iii) evaluate the effects of the alternative conceptual models that are consistent with available data and scientific understanding; and (iv) provide the technical basis for models used in the performance assessment. Thus, the purpose of the applicant's performance assessment is to meet regulatory requirements to provide a defensible demonstration of compliance with performance objectives.

Conversely, there is no requirement for the NRC, as regulator, to develop a performance assessment. It is the applicant's performance assessment that will form the basis for determining whether compliance with performance objectives has been demonstrated. An important purpose of independent performance assessment for the regulatory agency, however, is to develop risk insights to improve understanding of which processes, parameters, and alternative conceptual models are most important to repository performance. In addition, NRC and CNWRA staffs have gained important insights from the process of developing a complex performance assessment, such as the complex manner in which interrelations between various parameters and model uncertainties can affect estimates of potential repository performance.

A performance assessment developed by a regulator can be used to develop a better understanding of performance assessment issues through examination of alternative models and data sets. For example, a regulator may question whether certain conceptual models, inputs, or assumptions that may be included in a potential applicant's performance assessment model are appropriate given available information. In this case, the regulator could notify the potential applicant

that additional technical justification or an alternative analysis may be warranted, and the potential applicant may agree to provide such additional information. If the regulator has independent performance assessment capability, the regulator can use its own performance assessment model to analyze alternative approaches or bounding parameter values to assess the degree to which an alternative approach might affect performance. If the regulator's performance assessment analyses suggest that a particular technical issue is unlikely to affect potential repository performance, it may not be necessary for the potential applicant to submit a detailed justification on a technical issue that is of little overall importance. Conversely, if analysis indicates a technical issue may be highly significant to performance, the regulator will have a stronger basis for requesting that the potential applicant provide additional technical justification or adopt a revised approach.

Also to be considered are the complexity and level of uncertainty in site characteristics and design parameters. If, during the pre-application phase, a regulator has enough information to conclude that a particular site is sufficiently characterized and understood and that the design is sufficiently robust, there might be little need to develop independent modeling capability. A regulator might also choose to forego independent model development if sufficient information is provided by a potential applicant, and the regulator considers that the site conceptual model, modeling approach, and treatment of uncertainty are sufficient to enable the regulator to perform a review. A regulator would likely not gain additional risk insights by developing an independent model based on the same conceptual approach and treatment of uncertainty as contained in a potential applicant's model.

Considerations during development of independent performance assessment capability

Level of detail

For regulators who decide to proceed with development of an independent performance assessment model, budgetary and staff constraints will often necessitate development of models that are relatively simplified compared to a model developed by an applicant to support a safety case. This is not necessarily a problem or drawback. Since the regulator's goal is to develop a model that can provide risk insights with a total system context, a simplified model may be better suited to this purpose and permit more rapid adaptation for exploring alternatives and technical uncertainties. For example, the TPA code developed by NRC and CNWRA [1] uses a series of one-dimensional stream tubes to model radionuclide transport in the geosphere, whereas the most recent DOE model uses a fully three-dimensional particle-tracking approach to model radionuclide transport [2]. While the more complex DOE model incorporates a more detailed representation of the site geologic characteristics, the geologic representation is based on deterministic interpretations that can be difficult to update or modify to evaluate effects of geologic uncertainties on flow and transport. Conversely, the simplified one-dimensional approach used in the TPA model can easily be used to evaluate such uncertainties simply by varying or stochastically sampling input parameters related to transport distances and transport properties of geologic layers.

A regulator may also choose to include features, events, or processes in its independent model that may not be included in the model that the applicant is developing to support its safety case. For the regulator, evaluation of processes that may not be considered by the applicant in developing its safety case provides a useful method for evaluating the relative importance of alternative conceptualizations. It is important to note that the inclusion of alternatives in the regulator's model does not necessarily mean the regulator advocates or will require the same alternative conceptualizations to be part of the applicant's model. The insights gained from the alternative models, however, can provide the regulator with a basis for focusing its reviews on the justification provided by the applicant for excluding certain features, events, or processes.

Use of conservatism in the treatment of uncertainty

Abstracting complex processes into a performance assessment framework generally necessitates the use of simplifying assumptions and approximations that may not fully represent all aspects of the complex nature of a geologic repository system. Model developers, however, cannot ignore the need for conceptual models, model abstractions, and input parameters to represent essential features and key processes and to be technically defensible. One means of representing simplified model abstractions and approximations is to demonstrate that chosen approaches are conservative—that is, they bound performance relative to what more realistic and detailed physical representations would yield. While the use of conservatism in performance assessments is a generally accepted practice, there are several factors that need to be considered in applying this approach.

First, it is not always clear when a particular assumption or parameter estimate is a-priori conservative. Selection of a conservative parameter value or conceptual model based on process model assumptions may not necessarily lead to a conservative result for overall system performance because of non-linear interactions in the system model. In some cases, a more realistic parameter set or model may be necessary to capture the complexity of the system to the extent permitted by the state of the art in modeling, available data, and relevant uncertainties; or, it may be necessary to evaluate more than one simplified model abstraction (e.g., evaluating both high and low bounding estimates for the parameter) to ensure the effects on overall system performance estimates are sufficiently understood. Thus, regulators should attempt to evaluate system-level effects in adopting simplified assumptions that are thought to be bounding or conservative.

A second consideration is that the use of excessive conservatism may bias results in a manner that obscures the overall risk significance of other processes or parameters that are treated more realistically. This can make it difficult to evaluate uncertainties and sensitivities of system performance to specific parameters or models. For example, Mohanty and Nes [3] investigated the effects of using broad ranges of input parameter distributions on the identification and ranking of influential parameters to illustrate how rankings may change depending on the spread of input distributions. By evaluating parameter values that were substantially higher or lower than an assumed "realistic" value, they showed that, over the uncertainty range of a parameter, the model output sensitivity to the parameter could vary from being insensitive to highly sensitive, depending on the "level of conservatism" assumed. During iterative performance assessment development, it is important that the relative importance of modeled processes is properly understood so that future model iterations can be focused on the processes most important to the demonstration of safety. Because simplifying assumptions in complex safety analysis models is typically unavoidable, analysts should evaluate the effects of the assumptions or use alternative parameter ranking methods, such as component sensitivity analysis [4], to ensure that influential parameters are correctly identified.

A third factor to consider before adopting a conservative approach is the potential compounding effects on performance estimates when multiple conservative approaches are adopted. A truly conservative model abstraction or input value will produce system-level performance estimates demonstrably less optimistic than would be obtained from more realistic approaches. Compounding conservatisms, therefore, make performance estimates incrementally more pessimistic and may lead to conclusions about overall system performance that are inconsistent with real physical processes. Regulators should carefully consider the combined effects of conservative assumptions and strive as much as possible to improve realism in treating of uncertain processes and parameter estimates. In some cases, more realistic models may be needed to avoid overly conservative simplifications; in other cases, additional information may be warranted to obtain more defensible parameter estimates instead of using conservative bounding values or wide uncertainty distributions.

Role of independent performance assessment capability in developing risk insights

Application of risk insights to regulatory reviews

A regulator's risk insights are drawn from the process model analyses, information, and performance assessment analyses developed by a potential license applicant, and are enhanced by independent technical analyses and through the development and exercise of its own independent performance assessment tools. The risk insights provide a basis for focusing regulatory reviews on those aspects of a potential safety case that are most significant to waste isolation. A recent example of the NRC staff's understanding of risk information for the potential Yucca Mountain repository system is described in the Risk Insights Baseline Report [5]. This report groups risk insights for various features and processes into three categories of relative significance (high, medium, and low), based on contribution to, or effect on, the waste isolation capabilities of the repository system.

In addition to these risk insights, NRC also will consider the important barriers identified by DOE in their license application. NRC will give a high level of review focus to those aspects of the repository system identified by DOE in its license application as barriers important to waste isolation and also identified by the NRC as having a high significance to waste isolation. A high level of focus would also be given to those aspects of the repository system where DOE has identified those materials, structures, or features of the repository system as barriers important to waste isolation, but where NRC has identified that the comparable aspects of the repository system may have low significance to waste isolation. The NRC staff review would apply a moderate focus to areas where it has identified barriers as having high significance to waste isolation, but where the DOE has not identified the comparable materials, structures, or features as barriers important to waste isolation.

An example of this decision construct is described in Table 1. NRC uses a risk-informed approach to focus review efforts on the multiple barriers that may be put forward by DOE in its licensing case [6]. A more thorough discussion of how risk insights can be applied to a licensing review is provided by Leslie [7].

Table 1. Risk-Informed Logic for Determining the NRC Staff's Focus in its Review [7]

NRC Relative Significance	Identified by the DOE as Barrier	Level of Focus in NRC Review
High	Yes	High
High	No	Moderate
Low	Yes	High
Low	No	Low

Risk insights gained from independent performance assessment analyses

The Risk Insights Baseline Report [5] provides numerous examples of how independent performance assessment analyses can help to develop a better understanding of barrier capabilities. Below we focus on a single example of an evaluation of barrier capability that illustrates how risk insights can be developed and used, not only to focus the regulatory review process on risk-significant uncertainties, but also to guide the regulator in refining model abstractions in subsequent iterations of an independent performance assessment process. The example relates to the persistence of a passive oxide film on the surface of the waste package; this potential barrier was identified in the Risk Insights Baseline Report [5] as having high significance to waste isolation. The presence of a passive oxide film on the surface of the waste package outer barrier (consisting of Alloy 22) is anticipated to

result in very low general corrosion rates of the waste package. Under environmental conditions where a stable oxide film is maintained, corrosion is uniform and occurs at a slow rate. The risk ranking for this process was based in part on an analysis using the independent total system performance assessment code TPA Version 4.1j [1]. This performance assessment analysis [5] compared the calculated expected dose for two cases: (i) a base case, assuming passive conditions persist for all waste packages and (ii) an alternative case, assuming passive conditions are not maintained for 25 percent of the waste packages. As a result of the low corrosion rates under passive conditions for the base case, the predicted waste package failures from corrosion occurred at times ranging from 37,000 years to 403,000 years; the expected dose within 10,000 years was driven only by releases from assumed initial defects. For the alternative case, the absence of passivity was assumed to result in uniform corrosion rates that resulted in waste package failure times ranging from 400 to 4,000 years; the calculated expected dose was approximately 100 times greater within 10,000 years. A similar performance assessment analysis presented in the Risk Insights Baseline Report [5] concluded that the mode of corrosion failure (e.g., localized corrosion, uniform corrosion, or stress corrosion cracking) also can affect expected dose estimates because the failure mode affects the size of the opening that may allow water to enter a waste package. This analysis was done by limiting the amount of water assumed to enter waste packages exhibiting localized corrosion and not applying any limitation on waste packages affected by general corrosion. Based on this analysis, the corrosion failure mode was judged to be of medium significance to waste isolation. Given the high potential significance of passive oxide film persistence on the waste package surface and using the example of the decision logic in Table 1, NRC would assign a high or moderate level of focus on this issue during a licensing review, depending on whether DOE will take credit for this process as a waste isolation barrier component.

NRC and CNWRA also apply such risk insights for helping to determine when additional independent analyses may be conducted during the prelicensing period to improve understanding of the related uncertainties. For example, CNWRA conducted independent laboratory experiments [8] on Alloy 22, the proposed waste package outer barrier material, which confirms the assumption of slow corrosion rates so long as the passive film persists. These experiments also showed, however, that localized corrosion of Alloy 22 could occur in environmental conditions characterized by oxidizing or acidic, concentrated chloride containing solutions with low concentrations of inhibiting oxyanions. The results of these independent analyses then formed the basis for a revised performance assessment abstraction that is capable of explicitly evaluating uncertainties in the near-field environmental and chemical conditions that can lead to localized corrosion of waste packages surface and welded areas. In the revised performance assessment abstraction, localized corrosion can only occur if seeping water is able to contact the waste packages. The updated risk insights suggest evaluation of processes that could affect seepage water chemistry may be warranted to better understand the importance to waste isolation.

Conclusion

The preceding discussion provides an example of how independent performance assessment may be used to obtain initial risk insights that can provide a basis for updating and improving the performance assessment information in prelicensing activities. The improved data and models can, in turn, provide improved risk insights. Engaging in this iterative process of developing independent performance assessment capability enables the regulator to better understand how complex processes and their associated uncertainties can influence repository performance estimates. This iterative process helps to improve risk insights during the prelicensing period so that regulatory reviews of an applicant's safety case or a license application can appropriately focus on the processes and uncertainties that are most important to the demonstration of repository safety.

Acknowledgments

The authors wish to thank Bret Leslie, Osvaldo Pensado, Sitakanta Mohanty, and Lauren Mulverhill for their helpful technical and editorial insights.

This paper was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. NRC–02–02–012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of High-Level Waste Repository Safety. This paper is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC. The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of a license application for a geologic repository at Yucca Mountain.

References

[1] Mohanty, S., T. McCartin, and D. Esh (coordinators). "Total-system Performance Assessment (TPA) Version 4.0 Code: Module Descriptions and User's Guide." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2002.

[2] Bechtel SAIC Company, LLC. "Total System Performance Assessment—Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain—Input to Final Environmental Impact Statement and Site Suitability Evaluation." Rev. 00 ICN 02. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2001.

[3] Mohanty, S. and R. Nes. "The Effect of Conservatism on Identifying Influential Parameters." Proceedings of the 8th International Conference on Probabilistic Safety Assessment and Management (PSAM 8), New Orleans, Louisiana, May 14–19, 2006.

[4] Mohanty, S. NUREG/CP–0187. "Uncertainty and Sensitivity Analysis in the Context of Determining Risk Significance." Proceedings of the International Workshop on Uncertainty, Sensitivity, and Parameter Estimation for Multimedia Environmental Modeling, August 19–21, 2003. Rockville, Maryland: U.S. Nuclear Regulatory Commission. 2003.

[5] NRC. "Risk Insights Baseline Report." Washington, DC: U.S. Nuclear Regulatory Commission. 2004.

[6] NRC. NUREG-1804. "Yucca Mountain Review Plan: Final Report." Rev. 2. Washington, DC: U.S. Nuclear Regulatory Commission. 2003.

[7] Leslie, B. "Risk Insights Baseline Report: A Basis for Risk-Informed Decision Making in the U. S. Nuclear Regulatory Commission's High Level Waste Repository Safety Program for the Proposed Yucca Mountain Repository." Proceedings of the 8th International Conference on Probabilistic safety Assessment and Management (PSAM 8), New Orleans, Louisiana, May 14 – 19, 2006

[8] Dunn, D.S., O. Pensado, Y.-M. Pan, R.T. Pabalan, L. Yang, X. He, and K.T. Chiang. "Passive and Localized Corrosion of Alloy 22 —Modeling and Experiments." Rev.1. CNWRA 2005–02. San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2005.