Understanding Performance Assessment Results

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Abstract - *U.S. Environmental Protection Agency standards and U.S. Nuclear Regulatory Commission regulations applicable to the proposed Yucca Mountain repository were published in 200l. Both the standards and regulations specify use of a quantitative performance assessment to evaluate whether or not the proposed repository can comply with numerical safety limits for 10,000 years. Flexibility and diversity of the analytical methods used to evaluate repository performance are essential for understanding the behavior of a high-level waste repository due to the complexity of the system, the long time frame for the analysis, and the uncertainties associated with characterizing and representing the repository. These evaluations aid in understanding the relative importance of parameters, models, and assumptions used to represent the repository system and in identifying those system attributes that are relied on to limit radiation exposure. Important attributes of the repository system include the amount of water that can contact waste packages and waste, waste package degradation, degradation and release of the spent fuel, matrix diffusion in fractured rock units, and retardation of radionuclides in porous geologic units. This paper describes how a variety of existing analysis techniques can be used such that repository and barrier behavior is more transparent. Transparency in performance assessment results is improved by understanding (1) the hazard associated with each radionuclide in the waste, (2) the effectiveness of each attribute of the repository system to isolate waste, (3) the effect of uncertainty on estimates of performance, and (4) limitations in the technical basis supporting the performance assessment calculations.*

I. INTRODUCTION

EPA issued standards applicable to the proposed Yucca Mountain repository at 40 CFR Part 197 on June 13, 2001[1]. Subsequently, the Nuclear Regulatory Commission (NRC) published regulations for disposal of spent nuclear fuel and high-level radioactive wastes in the proposed geologic repository at Yucca Mountain, Nevada on November 2, 2001[2]. Both EPA standards and NRC regulations specify use of a quantitative performance assessment to evaluate whether or not the proposed repository can comply with numerical safety limits (e.g., annual, individual dose limit of 0.15 mSv [15 mrem]) for 10,000 years. The complexities of the repository system (e.g., long time frames, coupled thermal-hydrologic-chemical effects, slow processes difficult to measure with precision in the laboratory or observe in nature) make it necessary to use computer models to represent the many relevant features, events, and processes applicable to the potential repository. Computer models of complex systems not only permit estimates of overall performance (i.e., ability of the natural and engineered features of the repository system to limit radiation exposure), but also aid other analyses (e.g., sensitivity and uncertainty analyses) and calculation of other results (e.g., release rates, waste package lifetimes) that improve understanding of repository behavior. A variety of techniques and approaches are available to improve understanding of repository performance.

II. ANALYSIS TYPES

The final result of the performance assessment calculation is an annual dose, however, because this final result integrates the behavior of the repository over all the radionuclides in the waste and all the attributes of the repository system the annual dose, by itself, does not reveal detailed information for the repository system. We have examined how an understanding of the repository system can be improved by understanding: (1) hazard associated with high-level waste, (2) capabilities of the engineered and natural features of the repository system, (3) effect of uncertainty on repository performance, and (4) impact of limitations in the technical basis for the computer models used to represent the repository system.

Understanding performance assessment results must begin with an understanding of the hazard or risk associated with the variety of radionuclides contained in the waste. The hazard of each radionuclide is variable due, in part, to the amount of radionuclides present in the waste, the radioactive half-life of each radionuclide, and the radiation exposure associated with a specific radionuclide. In this paper we propose that a "hazard index" can be defined as the product of the inventory of a specific radionuclide and its dose conversion factor for ingestion (ingestion of radionuclides via the ground-water pathway is considered the most likely pathway for radiation exposure). This defined hazard index can provide a perspective on the importance of specific radionuclides relative to the amount present in the waste inventory and its significance for causing radiation exposures. Understanding the significance of individual radionuclides is important because many isolation attributes of the repository system can vary according to the specific characteristics of individual radionuclides.

Detailed understanding of the behavior of the repository system requires more than an understanding of the annual dose estimate of the performance assessment. A set of calculations, already made within the performance assessment, can be used to understand specific attributes of the repository system. This second set of calculations are intermediate calculations within the performance assessment that reveal the behavior of individual components or barriers of the repository system that are effective in isolating and/or containing waste. The engineered and natural barriers are specific attributes of the repository system that represent an inherent capability to limit the flow of water or radionuclides -- an inherent capacity that reduces any potential releases from the repository system. Engineered barriers are man-made repository attributes such as the waste package, spent fuel clad, and repository drift materials. Natural barriers arise from the geology and hydrology of the repository site itself, such as radionuclide sorption of specific geologic units in both the saturated and unsaturated zones. The effectiveness of individual barriers is difficult to understand using only the overall results (i.e., radiation dose) because overall performance is a measure of the combined effectiveness of all of the barriers each with varying capabilities that may overlap or mask the capabilities of other barriers. Additionally, many barriers provide capabilities that are radionuclide specific (e.g., radionuclide sorption, solubility limits). Consideration of a different performance measure, such as "delay time," offers an approach for understanding the capabilities of individual barriers and individual radionuclides, which can assist interpretation and understanding of the final dose estimate.

The performance assessment provides a basis for determining attributes of the repository system such as the delay times associated with the waste package (e.g., time for initial breach of the waste package due to corrosion processes), release rate for the spent fuel (e.g., time for release of radionuclides based on the intrinsic dissolution rate of the spent fuel matrix), release rate from the waste package (e.g., time for release of radionuclides from the waste package based on the amount of water entering the waste package and solubility limits), the unsaturated zone (e.g., time for each radionuclide to travel from the repository to the water table considering water flow and sorption properties of the unsaturated zone), fractured rock in the saturated zone (e.g., time for each radionuclide to travel in the fracture rock of the saturated zone to the saturated alluvium considering water flow in the fractures, matrix diffusion, and sorption properties of the rock matrix), and alluvium in the saturated zone (e.g., time for each radionuclide to travel in the saturated alluvium to the compliance location considering water flow and sorption properties of the alluvium).

An important aspect of the delay time values is that certain attributes, such as release rates and transport times, will vary by radionuclide due to variable radionuclide properties associated with solubility limits and sorption coefficients. Although the final dose result will reveal what radionuclides have an overall short delay time (i.e., those radionuclides that cause the initial doses) and those that have an overall long delay time (i.e., those radionuclides that are present in the inventory but do not cause radiation exposure), the delay times provide further information such as which attributes of the repository system cause the delay and the potential redundancy of attributes (i.e., significant delay in more than one barrier) that could be "masked" or hard to evaluate with just a final dose result. Thus, delay time information and the previous information on the hazard index provides a detailed understanding of the repository system useful for interpreting and directing sensitivity and uncertainty analyses.

A third set of analyses is designed to understand uncertainties and sensitivities associated with the repository system. Evaluation of repository performance is uncertain because of the complexity of the repository system and the long regulatory time period (i.e., 10,000 years). Sensitivity and uncertainty analyses are often used to examine the importance of individual parameters used in models that represent repository behavior. These analyses typically reveal that uncertainty in parameters associated with (1) amount of water that can contact waste packages and waste, (2) failure of the waste package, and (3) retardation coefficients for certain radionuclides have a significant impact on estimates of overall repository performance[3]. Consideration of alternative models is another means to examine the effect of uncertainty in modeling assumptions on estimates of performance and the capability of the barriers. Some important alternative models considered include those describing (1) degradation of the spent fuel, (2) effectiveness of matrix diffusion, (3) flow paths in the saturated alluvium, and (4) extent of the Calico Hills non-welded vitric unit in the unsaturated zone below the repository. The interpretation of the results of uncertainty and sensitivity analyses can be enhanced by understanding the relationship of the uncertainty and sensitivity in the context of the previously described hazard index and delay times. This is especially relevant for radionuclides that may have a high hazard index but do not figure prominently in sensitivity analyses because of long delay times (i.e., radionuclides that are delayed beyond the compliance period will not show up as sensitive in dose calculations).

A final class of analyses can be performed to provide insights on the potential limitations in the technical basis that supports the models used in the performance assessment. The impact of potential limitations can be evaluated with "what-if" analyses that assume less capability or degraded performance for specific attributes of the repository system. The analyses discussed earlier (i.e., barrier capability, parameter sensitivity and uncertainty analyses, and evaluation of alternative models) provide important insights on which attributes of the repository system provide significant isolation capability including the consideration of the hazard level of individual radionuclides and uncertainty. These insights can be used to explore the importance of potential limitations in the technical basis relative to the repository system. For example, degraded barrier analyses can be evaluated for important attributes associated with: (1) water flow into the repository, (2) failure of the waste package, (3) degradation of spent fuel, and (4) retardation of radionuclides in the saturated zone.

III. CONCLUSION

Flexibility and diversity of the analytical methods used to evaluate repository performance are essential for understanding the behavior of a high-level waste repository due to the complexity of the system, the long time frame for the analysis, and the uncertainties associated with characterizing and representing the repository. In the course of developing computer models of the repository system, the analyst, by necessity, acquires the capability to conduct a wide variety of evaluations. These evaluations aid in understanding the relative importance of parameters, models, and assumptions used to represent the repository system and in identifying those system attributes that are relied on to limit radiation exposure. Important attributes of the repository system include the amount of water that can contact waste packages and waste, waste package degradation, degradation and release of the spent fuel, matrix diffusion in fractured rock units, and retardation of radionuclides in porous geologic units. This paper describes how a variety of existing analysis techniques can be used such that repository and barrier behavior is more transparent. Transparency in performance assessment results is improved by understanding (1) the hazard associated with each radionuclide in the waste, (2) the effectiveness of each attribute of the repository system to isolate waste, (3) the effect of uncertainty on estimates of performance, and (4) limitations in the technical basis supporting the performance assessment calculations.

DISCLAIMER

REFERENCES

[1] NRC, "10 CFR Parts 19, 20, 21, 30, 40, 51, 60, 61, and 63 - Disposal of High-Level Radioactive Wastes in a Proposed Geologic Repository at Yucca Mountain, Nevada; Final Rule," November 2, 2001 (66 FR 55732).

[2] EPA, "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV," Final Rule, 40 CFR Part 197 (66 FR 32073; June 13, 2001)

[3] Codell, R.B., et al., "System Level Sensitivity Analyses, Using TPA Version 3.2 Code," NUREG-1746, Washington, DC, U.S. Nuclear Regulatory Commission, August 2001.