

**MULTIPLE BARRIERS: REGULATORY REQUIREMENTS
AND TECHNICAL AGREEMENTS FOR THE
PROPOSED YUCCA MOUNTAIN REPOSITORY**

W.L. Dam, T.J. McCartin, and J.R. Firth
U.S. Nuclear Regulatory Commission
Mail Stop T7F3, Washington, DC 20555

S. Mohanty
Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute, 6220 Culebra Rd., Bldg. 189
San Antonio, TX 78238-5166

ABSTRACT

Progress by the U.S. Nuclear Regulatory Commission (NRC) is presented in developing licensing requirements and technical agreements with the U.S. Department of Energy (DOE) relating to multiple barriers for the proposed Yucca Mountain high-level waste repository. Natural and engineered barriers are required to prevent or substantially delay movement of water or radionuclides. DOE will need to identify the important barriers of the performance assessment, describe each barrier's capability, and provide the technical basis for that capability. The emphasis is on ensuring that the repository system is robust and not wholly dependent on a single barrier. As a result, the system is more tolerant of failures. NRC staff review of DOE documents generated 11 comments on the multiple barriers approach. Subsequently, NRC and DOE staff met in a meeting open to the public to discuss these comments and DOE responses. During the meeting, the DOE demonstrated their approach for describing multiple barrier capabilities. DOE agreed to modify the approach and enhance preliminary documentation in areas such as data availability and simulation analyses; parameter and model uncertainty; spatial and temporal variability; independence and interdependence capabilities of barrier functions; and barrier effectiveness regarding individual radionuclides. This paper highlights regulatory requirements, staff review comments, and the agreements reached between DOE and NRC staff.

INTRODUCTION

Evaluating repository performance is complicated by the first-of-a-kind nature of the proposed facility and the long time period for the evaluation (i.e., 10,000 years). Analyzing complex, engineered structures is limited to a few hundred years of experience. Completely characterizing natural systems is difficult due to variabilities in materials and parameters. Thus, the post-closure performance objectives specified at 10CFR63 (1) require that a potential repository at Yucca Mountain, Nevada does not depend on a single barrier and must include both engineered and natural barriers.

Barriers are materials, structures, or features that prevent or substantially reduces 1) the rate of movement of water or radionuclides or 2) the release rate of radionuclides from the waste. Geologic barriers at Yucca Mountain include unsaturated and saturated volcanic and alluvial rock units that control water movement and radionuclide concentrations by processes such as infiltration, matrix diffusion, and sorption. Engineered barriers considered in DOE design options include titanium drip shields, double container nickel-alloy waste packages, fuel cladding, waste form borosilicate glass, and invert materials.

The multiple barriers requirement increases confidence that the performance objectives could be met, focuses technical reviews on key attributes essential to repository safety, shows how the repository would be more tolerant of unanticipated failures and external challenges, and enhances public confidence and communication of repository capabilities. Therefore, the purpose of the paper is to 1) provide an overview of the regulatory requirements for multiple barriers, 2) briefly describe the current DOE approach, and 3) describe the recent interactions between NRC and DOE staff leading to agreements on information needed in a license application, if one were to be developed.

MULTIPLE BARRIERS REGULATIONS

Specific NRC regulations in 10 CFR 63 referring to multiple barriers are cited as well as the regulatory basis supporting the multiple barriers requirements:

63.113 Performance objectives for the geologic repository after permanent closure:

- (a) The geologic repository must include multiple barriers, consisting of both natural barriers and an engineered barrier system.
- (b) The engineered barrier system must be designed so that, working in combination with natural barriers, radiological exposures to the reasonably maximally exposed individual are within the limits (e.g., individual, all pathway annual dose limit of 15 mrem). Compliance with this paragraph must be demonstrated through a performance assessment.
- (c) The engineered barrier system must be designed so that, working in combination with natural barriers, releases of radionuclides into the accessible environment are within the limits (e.g., individual, all pathway annual dose limit of 15 mrem). Compliance with this paragraph must be demonstrated through a performance assessment.

63.115 Requirements for multiple barriers. Demonstration of compliance must:

- (a) Identify those design features of the engineered barrier system, and natural features of the geologic setting, that are considered barriers important to waste isolation.
- (b) Describe the capability of barriers, identified as important to waste isolation, to isolate waste, taking into account uncertainties in characterizing and modeling the behavior of the barriers.
- (c) Provide the technical basis for the description of the capability of barriers, identified as important to waste isolation, to isolate waste. The technical basis for each barrier's capability shall be based on and consistent with the technical basis for the performance assessments.

Regulatory Basis for Requiring Multiple Barriers

The Nuclear Waste Policy Act of 1982 directed NRC to include multiple barriers in regulating geologic disposal of high-level radioactive waste. Requirements for multiple barriers were first codified in generic regulations 10 CFR Part 60 (2). Specific to Yucca Mountain, the NRC regulations 10 CFR 63 also include a requirement for DOE to provide specific information on barriers important to waste isolation. DOE has flexibility in designing the engineering barrier system and determining the extent of site characterization needed to show that the overall safety objective can be met. Attributes of the multiple barriers requirement relate to meeting the performance objectives, focusing technical reviews, and increasing public confidence.

Barriers help ensure performance objectives are met

NRC regulations in 10 CFR Part 63 adopts quantitative performance objectives for individual protection and human intrusion, and separate limits for groundwater protection conforming to EPA's final standards at 40 CFR Part 197 (refer to paper (3) in this volume for overall regulatory criteria). Demonstrating compliance with the post-closure performance objectives are adhered through conducting performance assessments (PA).

DOE's PA demonstrates how barriers of the repository system work together to achieve the performance objectives. DOE's PA is a systematic analysis that answers the following questions: What can happen? How likely is it to happen? What are the consequences? Because of the first-of-a-kind nature of the repository and the evaluation over a very long time period, significant uncertainty exists in the PA. Because of these uncertainties, 10 CFR 63 requires DOE to use multiple barriers in its post-closure PA.

Describing each barrier's capability to perform its intended function provides important information independent from conditions of the other barriers. For example, the natural unsaturated and saturated zones may provide significant retardation to many radionuclides such that some contaminants would not reach potential receptors within 10,000 years regardless of when the waste package fails. The capability of geologic systems to "retard" or slow the movement of radionuclides exists whether or not the waste package is breached. Describing the capabilities of the system's component barriers (e.g., retardation of specific radionuclides in the geologic media) can be accomplished by describing the applicable conceptual models and parameters used in the performance assessment. It does not require quantitative calculations beyond those performed in the PA to demonstrate compliance. The NRC believes that understanding the capability of the system's component barriers enhances understanding of the repository system, which in turn increases confidence that the post-closure performance objectives can be met.

Barriers focus reviews on aspects of repository safety

Requiring multiple barriers is designed to ensure that the repository system is robust and not wholly dependent on any single barrier. As a result, the system is more tolerant of failures and external challenges such as disruptive events. By providing a description of each barrier's capability and the associated technical basis for each barrier (e.g., retardation and matrix diffusion of radionuclides; waste package durability), information is provided that is essential to understanding how the natural barriers and the engineered barrier system work, both individually and in combination, to enhance repository safety. For example, sorption decreases the movement of radionuclides in the natural barriers and is independent of waste package lifetimes. The multiple barrier approach enables NRC reviewers to focus on key aspects of the repository safety by examining in detail the risk-significant aspects of the natural and engineering system.

Barriers provide confidence-building measures

In addition to protecting public health, safety and the environment, enhancing public confidence is another strategic goal at NRC (4). The multiple barriers requirement contributes to meeting this goal by providing documentation of each barrier's capability. Confidence is increased by requiring the use of a multiple barrier approach; specifically, an engineered barrier system is required in addition to the natural barriers provided by the geologic setting. The concept of multiple barriers is more readily understood by the general public than are the complex, technical details of a high-level waste repository. The natural

system of the repository surrounds the various components of the engineered barrier system which provide successive levels of protection. These descriptive results are easier to communicate than are factors affecting the engineered barriers, such as corrosion rates, or natural barriers, such as retardation factors and infiltration rates, which affect barrier capabilities and overall dose estimates.

EVALUATION OF APPROACH AND AGENCIES PRE-LICENSING AGREEMENTS

The NRC high-level waste program is focusing the pre-licensing work on topics most critical to post-closure performance of the geologic repository. Staff identified key technical issues (KTI's) for major processes, documented concerns, and reported on the process of resolving questions with DOE. Many of these issues relate to factors affecting the capabilities of the barriers. For example, rocks above or below the repository involve all geohydrologic mechanisms that control the flow of water, such as by diverting infiltration due to highly fractured welded and non-welded volcanic rocks. Natural barriers above the repository minimize the potential for contact of water with waste. Multiple Barriers is a subissue (i.e. significant topic) in the total system performance assessment and integration KTI (5). The NRC plan for reviewing a potential license application is to focus in-depth technical reviews on the natural and engineered barriers selected by DOE. Table I shows the relationship of several key technical issues to multiple barriers. The table identifies a few features, events, and processes (FEPs) that could influence barrier capabilities and therefore repository safety. These FEPs represent a small subset of the ones anticipated to affect barriers capabilities. For example, matrix diffusion is a process that could transfer radionuclides from mobile fracture zones to less mobile matrix regions of volcanic rocks. However, in the evolving near-field environment, coupled thermal-chemical-hydrologic processes may reduce the effectiveness of matrix diffusion by processes such as mineral precipitation that may coat fracture walls. Therefore, evaluating barrier capabilities involves examining all of the risk-significant features, events, and processes for each key technical issue.

Table I. Relationship of NRC's Key Technical Issues to Barriers

Key Technical Issue	Key Features, Events and Processes (FEPs)	Potential Repository Barriers Affected	Potential Attributes or Consequences
Total System Performance Assessment and Integration	Combines all risk-significant FEPs into abstracted models of repository system.	All Engineered and Natural Barriers	Evaluate barrier capabilities within the overall performance assessment.
Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC)	Infiltration, seepage, imbibition, advection, matrix diffusion	Unsaturated and saturated zone rocks	Diversion of infiltration and seepage
Evolution of the Near Field Environment (ENFE)	Coupled thermal-hydrologic-chemical (THC) processes	Unsaturated zone and engineered barriers	Repository design affects THC processes and other FEPs.
Container Life and Source Term (CLST)	Corrosion due to microbial activity, stress, and general processes	Drip Shield Waste Package Cladding Invert	Low corrosion rates facilitated by dilute chemistry and low water contact
Structural Deformation and Seismicity (SDS)	Rockfall Faults and fractures Earthquakes	Rocks in the unsaturated and saturated zones; Engineered materials	Repository designed to minimize rockfall damage and protect waste packages by drip shield and potential seismic events
Radionuclide Transport (RT)	Sorption onto geologic materials and colloidal transport	Unsaturated and saturated zone rocks	Sorption affects mobility of many radionuclides.

NRC and CNWRA staff have published articles on technical aspects of multiple barriers including the analyses of the engineered systems (6,7). These independent analyses facilitate the review and comment on DOE's multiple barriers approach.

DOE's Preliminary Approach to Multiple Barrier Requirements

During the pre-licensing consultation process, NRC staff (supported by Center for Nuclear Waste Regulatory Analyses experts), reviewed DOE's preliminary approach to identifying natural and engineered barriers in the Repository Safety Strategy (8) and TSPA-SR (9) reports.

DOE identified four natural barriers and five engineered barriers consisting of:

NATURAL BARRIERS

- Barrier 1. Surficial soils and topography
- Barrier 2. UZ rocks above repository
- Barrier 3. UZ rocks below repository horizon
- Barrier 4. Tuff and alluvial aquifers

ENGINEERED BARRIERS

- Barrier 5. Titanium drip shield
- Barrier 6. Alloy C-22 waste package
- Barrier 7. Commercial Spent Fuel cladding
- Barrier 8. A waste form (e.g. HLW glass)
- Barrier 9. A drift invert (e.g. crushed tuff)

DOE stated that the capabilities of barriers include:

- Limiting contact of water on waste packages by reducing infiltration
- Prolonging waste package lifetimes
- Restricting radionuclide mobility and release by limiting radionuclide solubilities
- Slowing transport away from the repository

DOE considered various approaches for evaluating barrier capabilities. PA results represented barrier behavior under expected and off-normal conditions. Degraded barrier analyses provided dose estimates when key properties were reduced and neutralized barrier analysis provided dose estimates when barrier properties were removed.

NRC Reviews and Independent Analyses

NRC staff comments provided to DOE revealed areas requiring further studies to gain a more complete understanding of barrier capabilities. Staff generated and transmitted 11 comments to DOE. Primary staff concerns relate to documenting the analytical approach and presenting results. NRC's goal is to conduct a systematic review that will seek to find that the following three questions are appropriately answered:

1. Is the identification of barriers adequate?

NRC staff found that while the techniques used to identify barriers presented in the DOE documents were acceptable, the documentation of the process used to identify important barriers needs to be clarified. For example, it was not clear if the identification of barriers is based on expected barrier capabilities or from tracing parameters from performance assessment analyses to identify barriers.

2. Is the description of barrier capability to isolate waste acceptable?

NRC staff commented that presenting dose curves alone are not sufficient for determining capabilities and understanding the movement of individual radionuclides and the mechanisms for controlling water or radionuclides. For example, what radionuclides are retained by the barrier and what moves through it? What are the important properties of the barriers, such as matrix diffusion, retardation factors, or corrosion rates? The potential for interactions between barriers with similar capability, such as the natural system above the repository and the dripshield, needs to be clarified to understand each barrier's capability. While the inert material, located beneath the waste packages, functions as a potential barrier with associated diffusional properties, the actual materials (such as crushed tuff or limestone) have not been determined. Model and parameter uncertainty associated with barriers is needed. Describing spatial and temporal variability of natural barriers in terms of barrier capabilities (or limitations) is needed. For example, how does time-dependent, environmental or physical-chemical variability of the system affect barrier capabilities (such as before and after the thermal pulse); dynamic conditions (e.g., mineral precipitation and fracture filling limiting matrix diffusion processes); and changes of rock properties (like transitions of vitric and zeolitic minerals in non-welded tuff units controlling variability in effectiveness for radionuclide retardation)?

3. Is the technical basis for barrier capability adequately presented?

The NRC staff raised specific questions and obtained agreements regarding the technical bases of barrier capabilities and modeling assumptions for several key technical issues as listed in Table 1. In addition, the staff anticipates that the DOE description of the technical basis will improve as the DOE finalizes the barriers approach and addresses agreements reached with NRC staff. One comment we provided was that the basis for correlations (or independence) between parameters in the models needs to be discussed appropriately.

NRC-DOE Technical Exchange Agreements

Staff met DOE on August 6-10, 2001 in a meeting in Las Vegas, Nevada to resolve the NRC's pre-licensing issues. Presentations provided by the DOE greatly clarified their approach to address the questions posed by NRC staff. From the technical exchange meeting between NRC and DOE, four areas requiring specific attention emerged: 1) addressing the capability of barriers with respect to the regulatory definition (e.g. prevent or substantial delay the movement of water or radionuclides); 2) uncertainty in conceptual models and parameters representing multiple barriers; 3) evaluation of spatial and temporal barrier properties (e.g., due to heterogeneity of rock properties, changing fracture properties), and; 4) describing the interdependence of barriers.

At the meeting, DOE agreed to provide 1) the final approach for presenting multiple barriers in FY2002 in the revised TSPA Methods and Assumptions report and 2) document barrier capabilities in the total system performance assessment supporting a potential license application in FY2003 considering: available data and analyses; parameter and model uncertainty; spatial and temporal variability in the performance of barriers; independence/interdependence capabilities of barrier functions; and barrier effectiveness regarding individual radionuclides. This information is expected to improve the NRC staff's ability to conduct a detailed review should a license application for Yucca Mountain be submitted. DOE indicated that the identification and description of multiple barriers will be refined based on comments provided by NRC staff.

SUMMARY

Substantial progress has been made over the past year at the NRC to develop licensing requirements and technical agreements with the DOE on issue resolution for the potential Yucca Mountain high-level waste repository. Demonstrating compliance with post-closure performance objectives specified in NRC regulations (10CFR63) requires that DOE, the applicant of a potential repository at Yucca Mountain, must include a system of multiple barriers. Barriers are an essential feature of the proposed high-level waste repository at Yucca Mountain. Attributes of multiple barriers enhances confidence in meeting the performance objectives by understanding the capability of the system's component barriers; focuses technical reviews by examining in detail the risk-significant aspects of the natural and engineering system; and facilitates public confidence because the concept multiple barriers is more readily understood by the general public than are the complex, technical details of a high-level waste repository.

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NRC's plan is to conduct a systematic review that will seek to find the appropriateness of each barrier's capability and technical basis. The performance assessment provides a systematic analysis of each barrier's capability including uncertainties. NRC staff generated 11 comments and transmitted these to DOE on the review of their preliminary approach to analyze and document multiple barriers. Subsequently, NRC and DOE staff met and reached two technical agreements. The DOE agreed to 1) provide the final approach for presenting multiple barriers in FY2002 and 2) document barrier capabilities in a potential license application in FY2003. Presentation of NRC multiple barriers regulation, NRC's review findings of DOE documents, and subsequent agreements with DOE are expected to improve DOE's identification and description of multiple barriers.

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