UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON NUCLEAR WASTE
WASHINGTON, D.C. 20555

September 9, 1998

The Honorable Shirley Ann Jackson
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

SUBJECT: ISSUES AND RECOMMENDATIONS CONCERNING THE NEAR-FIELD ENVIRONMENT AND THE PERFORMANCE OF ENGINEERED BARRIERS AT YUCCA MOUNTAIN

Dear Chairman Jackson:

This report presents issues related to the performance of the engineered barrier system (EBS) for the proposed Yucca Mountain High-Level Radioactive Waste (HLW) repository. The Advisory Committee on Nuclear Waste (ACNW) supports the NRC's view that both the natural setting and the EBS are key elements of a multiple-barriers approach for licensing a geological HLW repository.

The Committee highlighted review of the EBS as one of its first-tier priority issues for 1998. The Department of Energy (DOE) is placing increasing attention on engineered barriers as a means of ensuring that they have the most robust repository design reasonably attainable. Thus, the EBS is a significant topic for the Commission as the NRC staff reviews the DOE's Viability Assessment (VA) and prepares to move from prelicensing to licensing activities. The NRC's review of the license application (LA) will need to address the adequacy of DOE's concepts, data, and models used to support the EBS performance.

The Committee's advice on EBS is based principally on a working group meeting held June 10–11, 1998, at NRC headquarters during the 101st ACNW meeting. The main focus of the working group meeting was on the DOE and NRC work related to the reference repository design for DOE's Total System Performance Assessment – Viability Assessment (TSPA–VA) and on other engineered barrier options being considered. A panel of outside experts from academia and private consulting firms made plenary presentations. Experts from the NRC, the Center for Nuclear Waste Regulatory Analyses (CNWRA), DOE, and its contractors also gave presentations. International perspectives from Japan and Canada were presented.

Topics covered at the working group meeting included the following: water flow and chemistry, corrosion, radionuclide release and transport, total systems engineering approach, quality assurance and quality control, and modeling abstraction and verification. The working group served as a forum for discussing key issues and concerns related to EBS performance, the status of experimental, theoretical, and computer modeling studies related to engineered

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barriers, and the level of effort being devoted to those issues. There was a video conference link with both the CNWRA and the DOE Yucca Mountain Project Office in Las Vegas, Nevada, to facilitate technical interactions and to enable public participation. EBS issues related to excavation design were not addressed. ACNW plans to consider these issues early in 1999.

RECOMMENDATIONS

Based on our evaluation of EBS-related work to date, the ACNW has the following recommendations:

- The Office of Nuclear Materials Safety and Safeguards (NMSS) should evaluate its expertise in areas critical to the performance of the EBS and quality assurance/quality control (QA/QC) and should augment the currently available expertise where needed, by reinforcing NMSS with staff from other NRC offices, by hiring from the outside, or by engaging expert consultants.

- The Key Technical Issue (KTI) and subissue activities related to the EBS components and functions discussed in this report should be reexamined using risk insights gained from performance assessment and other risk analysis techniques.

- NRC should develop a systems engineering capability to allow it to use a total systems engineering approach in its evaluation of DOE's VA and in particular of DOE's LA.

- NRC staff should position itself through importance analysis or other risk-based techniques to evaluate the contribution of individual barriers to the overall system performance.

DISCUSSION

Availability of Expertise

Technical areas important to the evaluation of the EBS aspects of the VA and the LA for the Yucca Mountain repository in which the NRC and CNWRA have substantial expertise include water flow and water chemistry, corrosion, and radionuclide release and transport. In particular, the expertise and capability at the CNWRA are well respected in the community of corrosion scientists. Subareas in which additional expertise may be needed include the application of total systems engineering principles and QA/QC procedures to the evaluation of DOE's near-field activities. Where additional expertise is needed, NMSS should give consideration to augmenting its staff either from within or outside the agency. The CNWRA is currently using outside consultants in selected areas.

Water Flow and Chemistry

Limiting water access to the waste packages and waste forms is the most important requirement for ensuring the long-term containment of radionuclides. "Drip shields" and the use of drift backfill materials that divert water from the waste package (e.g., a "Richards barrier") are

among the methods that DOE is considering for limiting water contact with the waste packages. DOE is conducting drip tests in the Exploratory Studies Facility and also is working on a three-dimensional, drift-scale flow model. As part of its review activities, NRC should seek to identify and establish bounds for the most critical near-field environment processes.

The interaction of water with all the components of the EBS, and finally with the reactor fuel, poses an extreme challenge to understanding the complex processes that could lead to the mobilization of the waste. Examples of complex chemical problems that must be addressed include reactions with a concrete liner, the container and internal materials, the spent fuel, and backfill materials. The presence or absence of inorganic and organic chemical complexing agents or materials that can generate colloids is also important. NRC has developed a good understanding of the nature of the groundwater entering the repository, but additional scientific and engineering expertise may be needed to assess the relative importance of chemical processes in the drift (e.g., in the area of colloid chemistry).

Corrosion

Since the corrosion rate is primarily a function of temperature, water chemistry, and flow conditions, the details of the waste package design and the environmental conditions to which it may be subjected are critical to demonstrating long-term performance of this component of the EBS. Thus, the corrosion model is an essential element in defining the source term for radionuclide release and transport. Quantitative modeling of canister corrosion will require close attention to the engineering details of the design. This implies the need for NRC staff to develop more engineering-oriented mechanistic models of the waste packages than the Committee has seen in past presentations.

The reference design of the waste package involves three main barriers—a corrosion allowance material (CAM) for structural integrity; a corrosion resistance material (CRM) (the current choice is C-22, a high nickel-chromium-molybdenum alloy); and the fuel cladding. The long-term performance of the current waste package design (greater than 10,000 years) is primarily a function of the ability of the CRM to form and maintain a passive oxide film on its surface.

Demonstration of the long-term performance of C-22 or similar materials is a critical element of DOE's Repository Safety Strategy. Although the expected rate of corrosion is thought to be very slow, the experts agree that the long-term performance of C-22 is uncertain due to limited testing. To allow credit for the assumed long-term, corrosion resistance of this material, it is important to adequately bound the extreme environments that the material may encounter in Yucca Mountain over the long term (e.g., dripping, temperature, and pH) and to assess the crevice corrosion potential of C-22 in these possible environments. Until sufficient testing is done to rule out crevice corrosion, it will be necessary to make conservative assumptions about the long-term behavior of C-22. NRC needs to continue its evaluation of the adequacy of this aspect of DOE's corrosion program and to develop specific acceptance criteria for such materials.

NRC will need to determine whether or not DOE has considered realistic ranges of coupled chemical, thermal, and mechanical effects that may be experienced by the CRM. For example,

it is important to understand the potential for corrosion products of the CAM to impose stresses on the inner CRM barrier. These could lead to enhanced corrosion (i.e., stress corrosion cracking) and mechanical failure of the waste package at weak points, such as welds. Potential failure at welds is an area where the NRC needs to have DOE provide reliability data. The validity of the concept of a critical temperature regime, within which local corrosion of the CRM can occur, also needs to be evaluated.

Radionuclide Release and Transport

The NRC staff needs to be able to resolve questions about appropriate mobilization rates for the repository source term. There is a need for continuing work on secondary phases and colloids, including supporting confirmatory research, at the CNWRA. The dose to the critical population resulting from radionuclide releases to the biosphere is directly affected by the amount and kinds of radionuclides released and transported. This depends, in part, on the form of the waste. With the exception of the 10 percent of the total volume of the Yucca Mountain repository proposed to be devoted to defense high level waste (DHLW), the wastes stored at Yucca Mountain will consist of canisters of spent fuel from commercial nuclear power plants. The spent fuel is Zircaloy-clad uranium dioxide containing less than 1 percent of plutonium and less than about 4 percent of fission products. When the cladding fails, the fuel material will begin to dissolve. The extent and rates of dissolution will depend upon the pH, presence of complexing agents in the incoming water, formation of insoluble chemical phases, and the redox state of the water. The NRC staff has been evaluating the data and other information concerning cladding performance. NRC needs to continue this effort and to evaluate carefully the long-term corrosion issues raised about cladding in DOE's expert elicitation.

In order to characterize the repository source term, which determines the dose to the critical population, it will be necessary to know which radionuclides are mobilized, in what amounts, and how fast they transport. Currently, the release rates of radionuclides from the repository calculated by DOE are based upon fast-flow leaching experiments and solubility limits. These release rates do not necessarily account for the incorporation of radionuclides into secondary mineral phases formed by the degradation of spent fuel and DHLW glass. The repository release rate (i.e., source term) may be governed by the dissolution of these secondary phases. Currently, formation of secondary phases and associated mobilization rates are poorly understood. The release rates inferred from the Peña Blanca natural-analog site (which NRC has studied in detail) are two orders of magnitude smaller than DOE's spent fuel dissolution rates. Before such lower release rates can be justified for use in a performance assessment, the thermodynamic database for secondary uranium phases must be enhanced and studies of other potential solid phases with key radionuclides (especially neptunium) must be conducted. Resolution of questions about appropriate mobilization rates is of such potential importance that consideration should be given to supporting confirmatory research at the CNWRA.

The transport of important radionuclides in the colloidal form must be better understood under the conditions present in the repository and the environment surrounding the Yucca Mountain site. It is well known that colloids of plutonium may form under environmental conditions prevalent in the Yucca Mountain area. Other actinide elements, trivalent rare earth elements, and most transition metals (e.g., iron) may also form colloids, although not as readily as plutonium. Radionuclides that do not themselves form colloids may become chemically or

physically attached to "pseudo colloids" (colloids formed from other compounds such as clays or iron oxides). One area of particular importance is the potential of colloidal iron oxide degradation products of the CAM to adsorb radionuclides and enhance their transport. It is essential that NRC have chemical expertise available to evaluate these complex and important chemical factors.

Total Systems Engineering Approach

In an earlier ACNW report, the Committee expressed some concerns about the engineering capability of NMSS to provide the technical balance necessary to implement a total systems engineering approach.[1] The concern relates to the staff capability in engineering modeling. The NMSS team has established a high level of expertise in the earth sciences; the Committee believes there is a need to achieve comparable expertise in engineering science. This is particularly true in regard to the design of long-life, high-integrity, multiple-barrier containment systems. Among issues that need to be addressed are the following:

- The likelihood of different waste package environment scenarios, including the timing, quality, and rate of water accessing the waste package;
- A corrosion model that accounts for engineering details of design, including specific materials and material interfaces and configurations, temperature regimes, and surface wetting conditions;
- Consideration of alternative waste package degradation scenarios, including such design features as backfill or additional barriers.

The Committee believes that in order for the NRC staff to perform an adequate review of a system made up of integrated engineered features, it is necessary to have a total systems engineering capability.

Quality Assurance and Quality Control

The QA/QC measures used by DOE in constructing and operating the Yucca Mountain HLW repository must provide confidence that the repository will function as described in the LA. NRC must have the necessary QA/QC expertise to address the first-of-a kind situation represented by the proposed Yucca Mountain repository. It is essential that NRC staff begin to deal with the issues associated with QA of fabrication and the concomitant issues related to the pre-closure period for the repository, which could be several hundred years. Careful attention must be paid to the effects of corrosion on welds in the canisters and the eventual need for technical specifications and QA for waste package welds.

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[1] ACNW letter dated October 8, 1997, from B. John Garrick, Chairman ACNW to Shirley Ann Jackson, Chairman NRC, subject: "Comments on Performance Assessment Capability in the NRC High-Level Radioactive Waste Program "

The NRC also needs to consider the possibility that there may be an iterative, evolutionary approach to design, fabrication, and construction of engineered features (e.g., waste canisters and drifts) over the lifetime of the facility. For example, a change in canister design might introduce new safety issues.

The Committee recognizes that NMSS is taking action to enhance its QA/QC capability.

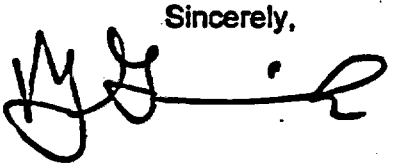
Model Abstraction and Verification

The process of abstraction used to develop a model of the overall EBS will tend to mask the assumptions and uncertainties that attend extrapolations. The NRC staff will need to be able to examine each of the suite of codes in the TSPA-VA model to ensure that the bases are adequate and that what is presented as first principle modeling is indeed relevant. The present lack of experimental validation of many of the TSPA-VA codes and subcodes adds to the uncertainty of the results. Finally, an assessment of DOE's model verification process is an important aspect of regulatory review.

SUMMARY

This report raises a number of important fundamental issues that the NRC staff should consider as it moves from prelicensing evaluations of the DOE VA to review of the EBS components of the license application. These include the following: augmenting expertise as needed; reexamining the KTIs and adjusting issues and subissues as necessary; developing a systems engineering analysis capability; and identifying the most important EBS components in terms of their capability to limit doses. The Committee has also identified specific technical issues in the areas of water flow and chemistry, corrosion, and radionuclide release and transport that need further consideration.

Sincerely,



B. John Garrick
Chairman