POLICY ISSUE
(Information)

August 29, 1994 SECY-94-228

FOR: The Commissioners

FROM: James M. Taylor
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SUBJECT: STATUS OF THE HIGH-LEVEL WASTE PERFORMANCE ASSESSMENT PROGRAM

PURPOSE:

To inform the Commission of the current status of the staff's program for performance assessment (PA) of a high-level waste (HLW) repository.

SUMMARY:

PA is an essential component of the U.S. Nuclear Regulatory Commission's HLW regulatory program, because it affords a systematic, quantitative method for analyzing and evaluating the safety of a geologic repository. PA synthesizes information from a wide range of scientific and engineering disciplines to achieve quantitative estimates of repository performance and to obtain an essential understanding of key repository processes, their interactions, and their implications for safety. The PA capability of the NRC staff is a vital contributor to: (1) the fulfillment of NRC's legislative mandates; (2) the development of NRC's waste disposal regulations; (3) the provision of guidance to the U.S. Department of Energy (DOE) on the adequacy of site characterization; and, eventually, (4) the support of a Commission decision on whether to grant authorization for construction of a proposed repository. The NRC staff is developing its PA capability in a time frame appropriate to review DOE's total system performance assessments (TSPAs) during the characterization, development, and licensing of the proposed repository. In a

NOTE: TO BE MADE PUBLICLY AVAILABLE AT THE COMMISSION BRIEFING ON SEPTEMBER 8, 1994

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cooperative effort between Center for Nuclear Waste Regulatory Analyses (CNWRA) staff, and Office of Nuclear Material Safety and Safeguards (NMSS) and Office of Nuclear Regulatory Research (RES) staffs, NRC has recently completed the second iteration of conducting quantitative PAs and acquiring analytical tools, thereby enhancing the staffs' PA capability.

BACKGROUND:

Since its inception in the mid-1970's, the NRC's HLW repository program has relied on PA to accomplish several objectives. It has been applied to the formulation of the NRC's HLW regulations (10 CFR Part 60) as well as to the generation of formal and informal comments on the U.S. Environmental Protection Agency's (EPA's) HLW standards at various stages of development.

DOE is required, by regulation, to provide a comprehensive PA in its license application. NRC is obligated to ensure in its review of a license application that the proposed repository will adequately protect public health and safety. The NRC staff's strategy for conducting a licensing review of DOE's PA calls for an audit review of the assessment in its entirety, supplemented by more detailed reviews of those sections that are of greatest safety significance, for example, radionuclide transport through fractures and the effect of specific scenarios such as volcanism. As a part of its review process, the NRC staff will rely heavily on site data collected by DOE, but will perform independent estimates of the potential performance of the repository, as described in the license application. It will be necessary, therefore, for NRC to decide which portions of DOE's assessment require independent verification through more detailed quantitative analyses.

NRC's PA activities have also supported pre-licensing interchange with DOE concerning characterization of the Yucca Mountain site. In its 1989 Site Characterization Analysis, the NRC staff commented on DOE's Site Characterization Plan, as required under the Nuclear Waste Policy Act, and highlighted the need for TSPAs early in the site characterization program. The staff expressed concern that DOE needed to improve the technical integration of its site characterization program and emphasized the important role that PA should play to integrate data-gathering activities and to guide evaluations of those data. PA activities have also supported NRC staff's interactions with EPA and the National Academy of Sciences (NAS), as a part of the NAS reevaluation of EPA's HLW standards, as they will apply to a proposed repository at Yucca Mountain.

The NRC staff will continue to rely on its PA activities to: (1) support ongoing interactions; (2) provide a basis for judging the sufficiency of DOE's site characterization activities; (3) facilitate constructive review and comment on DOE's Draft Environmental Impact Statement (DEIS); and (4) prepare for an effective and efficient review of an eventual license application.

DISCUSSION:

What is PA?

PA is a systematic safety analysis, similar to probabilistic risk assessment (PRA), that is especially adapted to the issues and systems relevant to the geologic disposal of radioactive waste. A PA quantifies the safety of a waste repository by estimating the nature and probability of radionuclide releases to the accessible environment and the potential impacts on public health and safety and the environment. Additional measures of total system or subsystem performance may also be quantified, using PA techniques. A PA is a structured analysis that systematically addresses the following:

(a) What are the conditions and events that could impact the performance of the repository?
(b) What is the likelihood of occurrence of these conditions and events over the mission time of the repository?
(c) What are the potential impacts of these conditions and events on repository performance?

To address these questions and to provide quantitative estimates of performance, an assessment must integrate and couple information from many scientific and engineering disciplines, including: hydrology, geology, geochemistry, corrosion science, stress analysis, rock mechanics, thermo-fluid dynamics, mechanical engineering, and PRA. PA has many complicating factors, including conceptual model uncertainty, probabilistic aspects, a hierarchy of models, and natural and engineered components in the repository system.

Modeling for assessing performance, by necessity, must be closely tied to site characterization and repository design. Data from site characterization and design features are crucial, not only to the development of appropriate conceptual models, but also to extraction of parameter values that are employed to obtain numerical estimates of repository performance. Development of the conceptual model or models is the first step in PA modeling. For most natural and many engineered systems, formulation of a single, acceptable conceptual model is difficult, if not impossible, to achieve. In most cases, several classes of conceptual models are derived that satisfy the known constraints to varying degrees. Conceptual model development includes decisions on the governing equations, the geometry of the system, initial conditions, appropriate boundary conditions, and level of detail. Formulation of conceptual models for the natural system introduces problems that may not be encountered for engineered systems. Engineered systems, within limits, can be designed; geology can only be explored and characterized. Because tests may perturb the very properties being measured and because of the possibility that destructive testing could impair the barrier properties of the site, site testing is usually quite constrained. The site conceptual model, therefore, is based on considerable extrapolation of sparse quantitative data, which can give rise to large conceptual and parameter uncertainty. In view of this, it is especially important that NRC use its PA capability to analyze alternate site models to test the robustness of DOE's conclusions.

PAs are probabilistic because they must treat a variety of scenarios (potential future states) and broad ranges of parameter values. Although the use of PA, like PRA, was pioneered by the NRC staff, it is still an evolving discipline, with substantial challenges. Also, like PRA, it is unlikely that PA will become an "off-the-shelf" technique. Quantitative estimates of repository performance are primarily obtained from the execution of a sequence of linked computer codes, representing various components of the repository system or its environment. Variations of parameter values are usually treated by repetitive execution of these linked computer codes using sets of input parameter values drawn from distributions with a probability assigned to each set of values. Uncertainties due to scenarios are treated by altering the models or distributions based on the nature of the scenario and repeating the calculation of performance, weighting the result with the probability of the scenario, which is determined by a separate auxiliary analysis. Because a large number of repetitions is required to treat the full range of scenarios and parameter uncertainties, the computer codes representing the various components of the repository system must be rapidly executable, yet sufficiently complete and detailed. These efficient, fast representations of elements of the repository are "abstracted" from more detailed, but computationally intensive, computer codes, based on fundamental principles and the properties of the system. These computer codes, in turn, rest on even more fundamental analyses and experiments. This "abstraction process" is shown schematically in the figure shown on the next page.

Models and corresponding computer codes for the total system that include realistic details of all system components can become very complex and computationally onerous. This is generally the case for repository PA. Under such circumstances, it is logical and appropriate to perform modeling using a hierarchy of models. The very detailed, and more realistic, models of individual processes comprise the first level of this hierarchy and are useful for understanding the sensitivity of a process to parameter variations and external forces. These first-level models are also used to demonstrate the conservatism of assumptions and to provide a basis for second-level models in the hierarchy. In the second level, a limited number of the detailed models, with some simplifications, are coupled with one another, to gain some understanding of the interfaces among processes. In the third and final level, all component models are further simplified and coupled to formulate a "TSPA model." These are the fast, efficient models required for a probabilistic treatment of performance. It must be kept in mind, however, that if the coupling among the detailed models is strongly nonlinear, then it may not be easy to ascertain whether assumptions for conservatism made in one model remain conservative when this model is coupled to another. In addition, not all processes are reduced to the third level of simplicity for inclusion in the system model; some processes are so central to the final result that they must be included in full detail.

A further complication for PA is that natural components are an integral part of the repository system. PA attempts to predict the behavior of a repository system over a very long period of time, currently 10,000 years. Furthermore, a natural subsystem, the geosphere, is a major component of the repository,

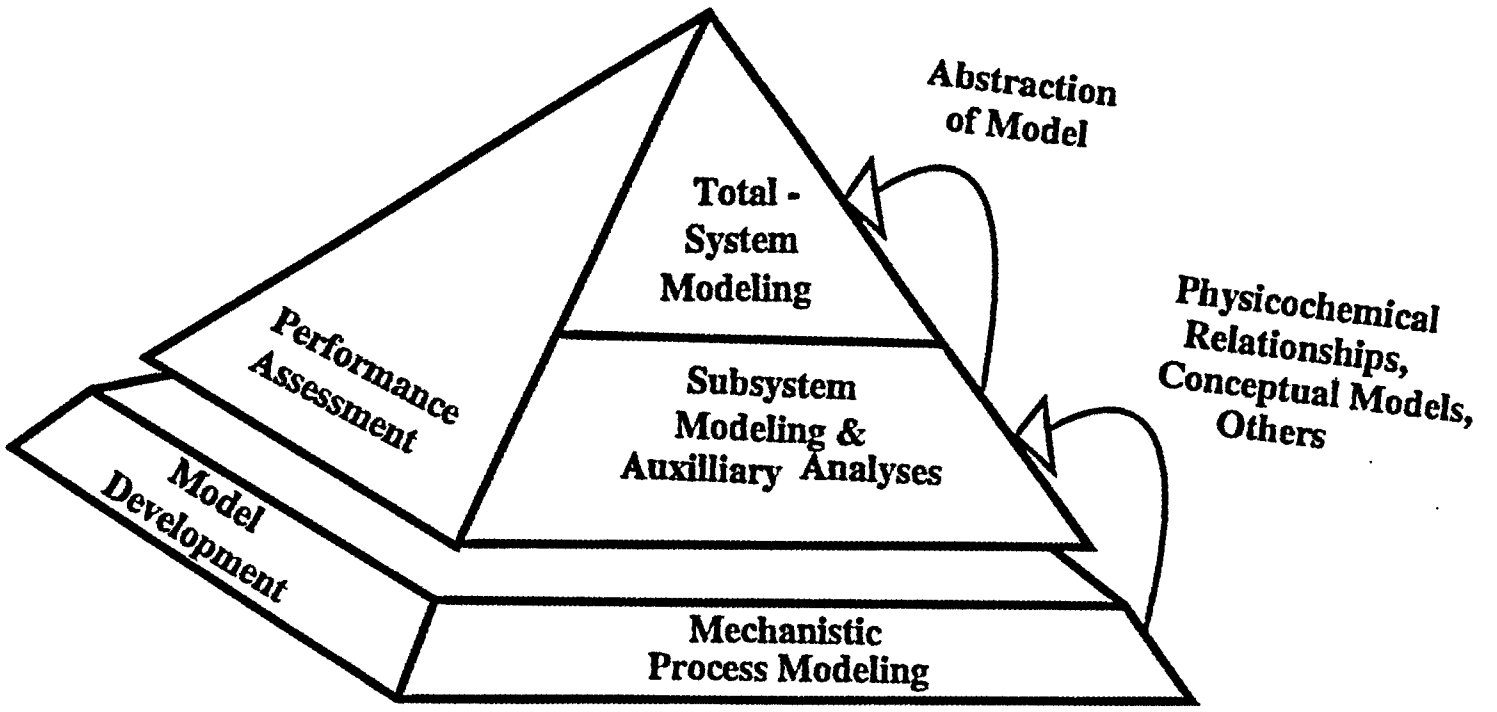

Figure: Model Hierarchy and Abstraction Process

playing a significant role in isolating the waste from the accessible environment, and interacting in complex ways with the engineered components of the repository. Because the geosphere itself functions as an integral part of the repository system, the natural system provides a barrier to isolate the waste, in addition to the engineered system. This is unlike other systems, such as a power reactor, where the natural system provides only the environment in which the reactor operates.

Validation of PA models is made difficult because: (1) the natural components can never be completely characterized; (2) the models for them are not unique; and (3) the long time period for performance precludes conventional testing of the models against experimental data. Because the repository system is expected to be robustly safe, there are many strategies that, conceivably, might be invoked to demonstrate compliance. For example, DOE could elect to take no credit for isolation of radionuclides by transport in the saturated zone at Yucca Mountain and rely solely on the isolation capability of the unsaturated zone at the site. Such a strategy could minimize the need for (and importance of) data about the saturated zone. The NRC staff must maintain a broad analytical capability to adjust to alternative compliance demonstration strategies as they are advanced and modified by DOE.

The NRC PA Program:

NRC's PA program offers both direct and indirect benefits to the HLW regulatory program. Direct benefits result because PA provides a basis for: (1) commenting on the adequacy of DOE's site characterization program and the assumptions made by DOE in its iterative total-system and subsystem PAs; (2) evaluating DOE's proposals for resolving specific technical issues during the pre-licensing period; (3) evaluating compliance determination methods to assist in the development of regulatory guidance; and (4) determining the feasibility of implementing existing regulatory requirements and the need for changes thereto. Indirect benefits include: (1) an improved understanding of the behavior of the mined geologic disposal system and the surrounding geologic medium; (2) improved translation of results obtained with quantitative models to support NRC pre-licensing and licensing review activities; (3) improved collaboration and coordination, among the HLW staff, of various technical and scientific specialties; and (4) development of information useful to identify and prioritize NRC-sponsored research.

PA activities are pursued in NRC's HLW regulatory program, to further specific objectives of the program. These objectives and supporting activities can be grouped into the following general categories: (1) fulfillment of NRC's statutory obligations; (2) continuing constructive pre-licensing interactions with DOE; (3) preparation of a license application review plan (LARP); (4) development of technical assessment capabilities; and (5) provision of general support to NRC's HLW regulatory program. A detailed discussion of these objectives and of the activities that support them is provided in the accompanying enclosure.

Accomplishments:

(1) Statutory Obligations

NRC has been an active participant in the recently-concluded public sessions of the NAS Committee on the Technical Bases for Yucca Mountain Standards. NRC staff relied heavily on its PA experience to formulate positions on various aspects of the EPA standard, including the specific questions raised by the Energy Policy Act of 1992. These views were presented to the committee at its opening session in May 1993. Over the course of the NAS Committee's public deliberations, the staff, assisted by the CNWRA, examined the NRC regulatory history of radiation protection standards related to waste disposal, reviewed all references in the regulatory history of Part 60 related to the persistence and effectiveness of institutional controls, and evaluated the written positions presented to the NAS Committee. Having completed these reviews, the NRC staff is satisfied that its formal views, presented to NAS in May 1993, continue to reflect staff's best judgment on the relevant issues, in light of its experience, to date. Staff's activities in support of the NAS Committee have been documented in a series of four memoranda from the Executive Director for Operations (EDO) to the Commission over the past 15 months.

In addition, NRC's PA experience has enabled the NRC staff to provide timely and detailed comments on EPA's final 40 CFR Part 191 environmental standards applicable to sites other than Yucca Mountain, as well as on draft Waste Isolation Pilot Plant (WIPP) compliance criteria (40 CFR Part 194) that EPA is developing and is expected to issue as a proposed rule in the Fall of 1994.

(2) Pre-licensing Interactions with DOE

The NRC staff conducts frequent and open interactions with DOE on issues related to PA. The staff has reviewed and commented on DOE TSPAs and subsystem PAs as they have become available. Since 1992, the NRC staff has conducted reviews of three major DOE PAs. From its interactions with DOE staff and reviews of ongoing DOE activities in PA, the staff has identified a number of areas related to PA, such as scenario methodology and use of expert judgment, for which NRC guidance is planned. Exercise of NRC staff's independent PA capability has enhanced NRC's participation in pre-licensing consultations with DOE on specific technical issues found to be important to repository performance and for which data are lacking.

(3) Development of a LARP

Based on staff's PA experience and using the Systematic Regulatory Analysis (SRA) process, the staff was able to identify five key technical uncertainties (KTUs) that directly pertain to PA. Staff's PA experience and activities are continuing to complement SRA by assisting in the identification, evaluation, and prioritization of KTUs, and by providing a means to focus NRC's limited resources on issues that are of greatest relevance to the determination of regulatory compliance. PA assists in focusing NRC's confirmatory research activities on the evaluation of the most significant KTUs.

(4) Technical Assessment Capability Development and Application

The NRC staff has applied its evolving PA capability through the conduct of two iterative performance assessment (IPA) exercises -- IPA Phase 1 and IPA Phase 2. Both exercises succeeded in demonstrating NRC's ability to conduct independent PA analyses and produced preliminary quantitative estimations of total repository system performance, using data available for Yucca Mountain, supplemented with numerous assumptions where data were not available. IPA Phase 2 expanded considerably on Phase 1, in that it incorporated better estimates of key geotechnical parameters, more scenarios and transport pathways, an improved uncertainty analysis and a dose assessment capability. This enhanced capability, developed in IPA Phase 2, includes a larger number of trained staff, more advanced models, and improved computer facility. This enhanced capability affords NRC increased flexibility to explore alternative interpretations and formulations of the repository system and to assess their impact on repository performance. Thus, NRC is better able to evaluate the assumptions made by DOE and to interact with DOE on those issues important to safety.

In addition to conducting total system IPA exercises, the staff has been developing and improving models and computer codes that contribute to a greater understanding of the geological, geochemical, hydrological, and corrosion phenomena that influence overall repository performance. The experience gained from this work has been directly applied to the evolution of staff's IPA system code, which provides a working platform from which staff can evaluate DOE's concepts and models.

(5) General Support of NRC's HLW Regulatory Program

Because the development of PA methodologies is being pursued vigorously in the international community of nations with ongoing repository programs, NRC staff participates in a number of international PA activities as actively as resource constraints allow. NRC participation in these international efforts thus far has allowed the NRC staff to stay abreast of new developments, obtain broad-based peer review of NRC's PA program and activities, and leverage limited staff resources to augment its technical capabilities.

In addition to participating in international HLW activities, the NRC staff frequently briefs the Advisory Committee on Nuclear Waste (ACNW) on selected PA topics of interest to the Committee and, periodically, on the staff's overall PA capabilities and activities. The NRC staff and the CNWRA participated in an all-day briefing of the ACNW on May 16, 1994, on the subject of NRC staff's capabilities in computer modeling and PA for the HLW regulatory program. Also, results from IPA Phase 2 specific to thermal effects have been presented to the Nuclear Waste Technical Review Board at its request.

Plans for Future Work:

To document the goals and required activities of NRC's HLW PA program, the staff is in the final stages of developing an initial Performance Assessment Strategic Plan (PASP). This planning document defines in detail the specific activities that support the staff's HLW regulatory program, as discussed for the five activity areas identified earlier in this paper, and that are discussed in more detail in the enclosure. The first version of the PASP will pertain to compliance with post-closure performance objectives and will be confined to activities planned up through the receipt of the DOE license application. Future versions will be modified to address compliance with pre-closure performance objectives and will include activities planned through repository closure. The goals and activities identified in this paper and in the PASP are consistent with, and are intended to complement, the NRC staff's overall review strategy, as presented in NUREG-1495. Near-term applications of PA planned in each of the activity areas are described more fully in the enclosure and are summarized below.

(1) Statutory Obligations

NRC staff experience gained in PA will be brought to bear, as stated above, to evaluate the findings and recommendations of the NAS (expected in December 1994); to support NRC review of and comments on EPA standards that will be developed pursuant to those recommendations; and to assist in the determination of conforming amendments to Part 60. Staff will draw heavily on its PA experience, along with a more fully developed PA capability, as it prepares to review and comment on DOE's DEIS.

(2) Pre-licensing Interactions with DOE

DOE has committed to a program of IPA and the integration of PA with its design and site characterization activities. Following a preliminary publication in 1990, DOE has issued PAs in 1991 and 1993. The staff is currently reviewing the 1993 TSPA prepared by Sandia National Laboratory for DOE and a more limited PA prepared by TRW Environmental Safety Systems, Inc., the DOE Management and Operating Contractor. DOE projects that additional PAs will be issued in FY95. In the future, the staff expects PAs to be submitted periodically and to accompany other documents supporting design and site-suitability evaluations. The implications of major technical investigations, such as the thermal-loading experiments on a large block of tuff at Fran Ridge, are expected to be reflected in subsequent PAs.

(3) LARP

Insights from PA, and, in particular, the insights obtained from IPA Phase 2 and the review of recent DOE TSPAs, will be applied to the integration review of the LARP. At present, the LARP contains KTUs, which are identified at varying levels of detail, which may be duplicative, and which are not grouped in similar technical areas. PA will aid in the integration review intended to resolve these issues. In addition, PA will be useful to determine if additional KTUs are needed to address issues related to interdisciplinary

topics and interfaces, which may not have been previously identified.

(4) Technical Assessment Capability

As its PA model and code development work matures, the staff will shift from development toward applying this capability to resolution of technical, regulatory, and programmatic issues. In particular, the staff will be shifting their emphasis, in IPA Phase 3, toward applying methods and skills to the resolution of programmatic issues and the evaluation of additional site characterization data. Additional models and computer code development will be undertaken to the extent necessary to resolve new technical issues as they arise or to maintain a state-of-the-art capability as the technology continues to advance.

For example, alternative strategies for thermal loading of the repository have been advanced by DOE recently as a means to enhance repository performance. The "extended dry" repository design concept attempts to delay waste package corrosion and fuel dissolution in groundwater by using higher areal thermal loading densities to dry out the rock near the buried waste for a relatively long period of time. Although this strategy may be beneficial, it raises a number of technical issues, including:

(a) Will higher temperatures for a longer period of time enhance the flow of hot vapor past the waste packages, concentrating salts, and creating a corrosive environment that outweighs any advantages of drying?

(b) Will higher temperatures over longer times heat the host rock such that the rock is altered, thermal stresses are induced, and the waste packages are subjected to a disadvantageous mechanical and/or geochemical environment?

(c) Will the actual performance of the repository improve, but will the uncertainties in calculating the performance increase because of the higher operating temperature and the longer thermal period, so that licensing decisions become extremely difficult?

The NRC staff will apply its PA expertise to the evaluations of these and similar questions, as DOE's repository design evolves.

(5) General Support of NRC's HLW Regulatory Program

Staff will continue to participate in selected international PA activities, to leverage available staff resources, and to facilitate licensing by obtaining international acceptance of technical and regulatory approaches. In particular, NRC has gained great benefits from its participation in the Organization for Economic Cooperation and Development, Nuclear Energy Agency, Performance Assessment Advisory Group, and activities sponsored by that organization. Staff has also participated, on a limited basis, in the international study BIOMOVS, addressing issues in dose modeling related to waste management. PA staff will assist the Division of Waste Management (DWM) in communicating with the Commission, the ACNW, EPA, and other Federal

agencies. In particular, PA is expected to help set priorities across disciplines and to help integrate related technical activities.

Also, to realize the maximum efficiency and benefit from the newly reorganized DWM, the staff is exploring a number of ways to enhance the interaction between its HLW and low-level waste PA programs. Modeling experiences and, in some cases, modeling tools, may have direct applicability in more than one area. Furthermore, a larger group of analysts, all working in PA, provide a depth of coverage for the various disciplines needed in PA, to facilitate progress on critical activities.

Potential Impacts of DOE's Proposed Program Approach on NRC's PA Program:

DOE has recently articulated a Proposed Program Approach (PPA) that realigns the stated goals and schedules for its repository program. As indicated in a July 1, 1994, memorandum from the EDO to the Commission, the staff is carefully reviewing the PPA, but does not, at this time, have sufficient information to either object to, or support, DOE's new approach. The August 25, 1994 memorandum from the EDO to the Commission, which provides a more detailed analysis of the PPA, is consistent with this view. With respect to PA, staff has identified a number of potential concerns that could have significant impacts on NRC's program.

The PPA advanced by DOE essentially shifts the acquisition of a substantial amount of data from the pre-license application stage to the post-license application stage. In addition, it couples data collection to phased decision-making on site suitability, preparation of an environmental impact statement (EIS), and completion of a license application. According to the schedules indicated by DOE's approach, a decision on site suitability will be made in 1998, accompanied by the publication of a DEIS the same year; the final EIS will be published in 2000; and the license application will be submitted in 2001. Considering that DOE will need some time to process and review data before including data in these documents, time available for actual data collection can be expected to be somewhat shorter than the above dates suggest. This represents a significant change in DOE's strategy for licensing a HLW repository. It now appears clear that DOE expects to base its site suitability and licensing decisions on a much sparser database than was contemplated when the SCP was written. DOE proposes to reach decisions based on more limited data by relying on what is referred to as "bounding analyses" for many key technical issues.

NRC's review of a license application prepared under this approach will be based, of necessity, on the same sparse data. In response, the basic NRC strategy of subjecting the entire DOE submittal to audit reviews and selecting critical parts for detailed review and independent verification will become even more important, although independent verification of critical parts may become more difficult. With sparse data, NRC will have to assess a larger number of assumptions, more system conceptualizations, and larger parameter uncertainties. To determine whether DOE's bounding analyses are indeed bounding under such uncertainties may require NRC to perform (or ask DOE to perform) alternative analyses. For example, DOE appears to anticipate

resolving site-related issues one at a time, before total-system analyses are completed. However, the critical bounding levels for subsystems and components depend, to a great degree, on their interactions within the total system. Determining bounding values for infiltration rate, extent of fracturing and faulting, transport properties of fractures and faults, possible effects of heat on rock and contained fluids, probability of volcanism, and values of geochemical sorption will be problematic, because no system is robust enough to sustain values with very wide bounds. DOE selection of "realistic" bounds to get around these difficulties may be controversial at best, especially in the absence of reasonably complete total-system analyses that support DOE's bounding assumptions.

NRC may find it necessary, for example, under DOE's proposed approach, to redirect its SRA effort to focus on completing those compliance determination methods that relate to requirements of the 10 CFR 60.122 siting criteria, accelerate plans for reviewing Title I repository and Title II waste package designs, and more actively pursue rapid development of its PA capabilities so that the impact of differing or alternate assumptions on system performance can be evaluated in a timely manner.

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Enclosure:
Objectives and Activities of
NRC's HLW PA Program

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Objectives and Activities of NRC's High-Level Waste Performance Assessment Program

Enclosure

OBJECTIVES AND ACTIVITIES OF NRC'S HIGH-LEVEL WASTE PERFORMANCE ASSESSMENT PROGRAM

1. STATUTORY OBLIGATIONS

Performance assessment (PA) activities conducted to support the Commission in the fulfillment of its near-term statutory obligations are directed toward ensuring a sound regulatory framework, providing early feedback to the U.S. Department of Energy (DOE) on its site characterization and design program, and ensuring that DOE's site characterization program will produce sufficient data to support a high-quality license application. The statutory framework within which the U.S. Nuclear Regulatory Commission must execute its high-level waste (HLW) regulatory responsibilities is defined by the requirements of the Atomic Energy Act, as amended, the Nuclear Waste Policy Act of 1982 (NWPA), as amended, and by the Energy Policy Act of 1992 (EnPA). Before receipt of a license application, NRC is obligated to modify its regulations consistent with final U.S. Environmental Protection Agency (EPA) standards for Yucca Mountain; review and comment on DOE's site characterization plans and schedules; and provide preliminary comment on the sufficiency of the DOE in-depth site characterization analyses and waste form proposals, all in advance of any DOE recommendation of a site for development as a repository. Furthermore, in 1989, the Commission adopted final regulations, at 10 CFR Part 51, which defined its responsibilities and procedures under the National Environmental Policy Act (NEPA), with respect to a geologic repository. At that time, the Commission committed to conduct a thorough review of DOE's Draft Environmental Impact Statement (DEIS) and to provide comments regarding its adequacy. The Commission also stated its intent, consistent with the NWPA, to adopt DOE's Final Environmental Impact Statement (FEIS), to the extent practicable. NRC's independent PA capability will be essential to support the review of DOE environmental impact statements.

Under the provisions of the EnPA, EPA was required to commission a study, with the National Academy of Sciences (NAS), to advise EPA on the technical bases for standards applicable to the Yucca Mountain site. NRC has been an active participant in the recently-concluded public sessions of the committee convened by NAS to conduct this study. NRC staff relied heavily on its PA experience, to formulate positions on various aspects of the EPA standard, including the specific questions raised by the EnPA. These views were presented at the committee's opening session in May 1993. Over the course of the NAS' public deliberations (conducted between May 1993 and April 1994), the staff, assisted by the Center for Nuclear Waste Regulatory Analyses (CNWRA), examined the regulatory history of NRC radiation protection standards related to waste disposal; reviewed all references in the regulatory history of 10 CFR Part 60, related to the persistence and effectiveness of institutional controls; and evaluated the written positions presented to the NAS Committee. Having completed these reviews, the NRC staff is satisfied that its formal views, presented to the NAS in May 1993, still reflect staff's best judgment on the relevant issues, in light of its PA experience, to date. Once NAS issues its findings and recommendations at the end of 1994, the staff will carefully review and evaluate them, so that NRC will be prepared to provide meaningful review and comment on the final EPA standards and will be able to determine what conforming revisions to Part 60 these new standards will necessitate. PA analyses provide the bases for continuing evaluations of

NRC's Part 60 requirements, including those revisions necessary to conform to final EPA standards, to resolve regulatory and technical uncertainties related to their implementation. Staff's activities in support of the NAS Committee have been documented in a series of four memoranda, from the EDO to the Commission, over the past 15 months.

2. PRE-LICENSING INTERACTIONS WITH DOE

Frequent and open interactions with DOE on issues related to PA are essential prerequisites to reaching agreement both on the PA methodology best suited to the Yucca Mountain site and on appropriate methods for demonstration of compliance with NRC's regulations. Staff activities supportive of such interactions with DOE fall into three general areas: (1) reviews of DOE's total-system and subsystem performance assessment, related topical reports generated by DOE, and DOE's license application annotated outline; (2) participation in PA-related technical exchange meetings, technical meetings, and quality assurance audits; and (3) development of appropriate regulatory guidance to address PA issues.

PA activities, both at NRC Headquarters and at the CNWRA, play an integral role in supporting the NRC staff's most important technical reviews. Among those technical reviews for which PA analyses will contribute heavily are: reviews of DOE site characterization plan (SCP) progress reports, SCP study plans, periodic Early Site Suitability Evaluation reports, repository and waste package designs, waste-form proposals, and site characterization analyses. Reviews of DOE's pre-licensing activities and documents focus on providing guidance to DOE on site characterization requirements, ongoing design work, and licensing issues important to DOE's development of a complete and high-quality license application. Staff members periodically take part in formal technical meetings with DOE, its contractors, and other interested stake holders, to review and consult on interpretations of data, to identify potential licensing issues, to discuss the sufficiency of available information and data, and to discuss methods and approaches for the acquisition of additional information and data.

Out of such interactions with DOE has emerged the recognition of a number of areas, related to PA, for which NRC regulatory guidance to DOE would be beneficial. To date, five areas have been identified in which the staff intends to develop guidance. These include: (1) the elicitation and use of expert judgment; (2) acceptable definition of scenarios and means for appropriately estimating their probability of occurrence; (3) the proper construction of complementary cumulative distribution functions (CCDFs) of radionuclide releases to the accessible environment over the 10,000 years, currently prescribed in the containment requirements of EPA's standards; (4) model validation strategy; and (5) transport of radionuclides through the biosphere. At present, staff is concentrating its guidance development activities on the first and fourth of these.

DOE is expected to make extensive use of expert judgment in developing its PAs. To be in a position to critically evaluate their use, the NRC staff has begun addressing the issues and techniques associated with the elicitation and use of expert judgment in PA. Staff is attempting to develop a foundation on

which it can provide guidance to DOE on the acceptable use of formal judgment elicitation techniques. The emphasis of such guidance will be on techniques for selection of experts, identification of topics for which expert elicitation is appropriate, structuring of the elicitation process, and documentation of the process. Recently, the CNWRA completed an expert judgment elicitation exercise for future climate scenarios in the Yucca Mountain region. As a result, NRC is now able to comment on specific aspects of DOE's use of expert judgment; has enhanced its own capability to elicit and use expert judgment; and has a better understanding of climate change at Yucca Mountain.

Scenario development is another area for which NRC guidance is necessary. In the staff's analysis of DOE's SCP, concerns were raised with regard to logical and mathematical inconsistencies in DOE's usage of the term "scenario" and in approaches used to decide on the inclusion or exclusion of scenarios in the demonstration of compliance with Part 60 requirements. Methods for determining the probabilities of plausible future states of the repository environment (e.g., faulting, climate change, volcanism) are not well-established, especially over long regulatory time frames. Guidance is needed to clarify NRC's expectations with respect to what constitutes acceptable procedures for defining relevant scenarios, for estimating their probabilities, and for conducting the scientific investigations necessary to support such estimates.

Depending on the ultimate form of the final EPA standards, the results of DOE's PA may be required to be displayed as CCDFs that indicate the probability of exceeding various levels of radionuclide release or of exceeding some specified health risk or dose limit. (The CCDF is a standard means to display probabilistic information and is likely to be used whether specifically mandated or not.) Thus, the CCDF is a fundamental indicator of whether compliance with the EPA standards and with NRC's implementing regulations has been demonstrated. The staff is quite concerned, therefore, with the process whereby DOE decides that a given condition, process, and/or scenario does not impact the performance of the system sufficiently to be considered in the construction of the CCDF. As a part of its Iterative Performance Assessment (IPA) effort, the staff will evaluate different means for generating the overall CCDF for cumulative releases, and can then provide guidance to DOE, to ensure that the approach DOE selects is scientifically defensible and allows for the construction of a CCDF that has meaning for protecting public health and safety.

Validation of models used in PA is likely to be a major issue, in the licensing of a repository, because demonstration of compliance will depend largely on results from the application of predictive models. The usual procedures for validation of predictive models with engineered systems (i.e., comparison of model predictions to experimental results) is precluded for the temporal and spatial scales of interest to repository performance. Consequently, a strategy that will provide an acceptable degree of validation (e.g., partial validation) is needed. The NRC staff is participating in a joint effort with the Swedish Nuclear Power Inspectorate (SKI) aimed at developing a regulatory perspective on validation of PA models. This activity will produce a White Paper discussing the regulatory issues related to

validation and potential strategies for the resolution of these issues specifically related to the evidence that could be used to demonstrate confidence in the models. In addition, NRC, through its own research-funded efforts and active participation in other multi-lateral validation activities such as INTRAVAL (INternational TRAnsport VALidation), is developing a basis for preparing the aforementioned guidance on model validation.

The NRC staff will need to be in a position to evaluate and employ models and codes that are used to estimate radionuclide migration in the biosphere, to predict health consequences from repository releases. Expertise in this area will be of even greater importance if final EPA standards are adopted that establish dose as the primary performance indicator. The NRC staff has long supported a health- or risk-based standard expressed, instead, as a limitation on a derived quantity, such as quantity or concentration of radioactive material released to the environment. A standard based on dose or risk to the individual could be made workable, in the staff's view, if such a standard could be applied in a reasonable manner and could be implemented using a reference biosphere. In the event that the NAS recommends, and EPA adopts, a health- or risk-based standard, expressed as a dose or risk limit, it may be necessary for the NRC staff to augment its PA methodology. To evaluate the potential impact of individual dose or risk as a performance indicator, a number of activities are planned to address the considerations peculiar to implementing such a criterion. First, the HLW PA program intends to tap expertise already resident in NRC's low-level waste program related to the assessment of exposure pathways for determining compliance with 10 CFR Part 61. Other sources of expertise on exposure pathways assessment include NRC staff involved with risk assessment studies for nuclear materials facilities, power plants, and decommissioning studies. Second, because the current NRC expertise on exposure pathways assessment has been applied primarily to short-term regulatory periods (e.g., operating facilities), the NRC staff is participating in international activities, such as the BIOsphere MOdel Validation Study (BIOMOVS), to take advantage of experiences in other radioactive waste disposal programs that are analyzing the level of confidence that can be placed on predictions of biosphere transport for radionuclides over thousands to hundreds of thousands of years. Information generated from these activities will allow the NRC staff to develop the models and codes necessary for estimating compliance with an individual dose performance measure, should it be included in a revised EPA standard.

3. DEVELOPMENT OF A LICENSE APPLICATION REVIEW PLAN (LARP)

NRC, working with the CNWRA, established the Systematic Regulatory Analysis (SRA) as the means to identify key technical uncertainties (KTUs), uncertainties that are significant to repository performance and that DOE should address during site characterization. Thorough identification and documentation of the KTUs are fundamental to the development of a LARP, as the NRC staff must pay particularly close attention to DOE's resolution of KTUs during the license application review. The SRA process was able to identify a number of KTUs that directly pertain to the conduct of PA. Among these are: (1) uncertainty in the conceptual models used to define or describe the repository system; (2) uncertainty with respect to the assumptions and simplifications adopted in the development of mathematical models and computer

codes; (3) uncertainty arising from the variability of input parameters; (4) uncertainty with regard to the prediction of future system states; and (5) uncertainty in the validity of PA models. PA is continuing to complement SRA by assisting in the identification, evaluation, and prioritization of KTUs, and by providing a means to focus NRC's limited resources on those issues of greatest relevance to the determination of compliance. PA also provides a basis for directing NRC's confirmatory research activities to the evaluation of the most significant KTUs.

PA methodology can and will be applied by the staff to evaluate the effectiveness and implementability of current regulations and to assess the need for additional rulemaking. Taken together, the results of SRA and staff's experience with PA are being used to support the development of regulatory guidance documents, review plans, staff technical positions, and, where necessary, rulemakings, all of which will contribute to the reduction in overall uncertainty in the pre-licensing and licensing processes.

4. TECHNICAL ASSESSMENT CAPABILITY

To critically evaluate DOE's analyses supporting compliance demonstration, it is essential that NRC develop and maintain an independent understanding of the processes and conditions significant to long-term repository performance. The NRC staff has undertaken two primary activities to cultivate, in-house, the necessary independent technical assessment capability: (1) IPA exercises conducted by the staff and the CNWRA; and (2) the generation and refinement of models and computational tools (i.e., computer codes) for specific components of the repository system (e.g., geology, hydrology, geochemistry, and the engineered barrier system).

IPA exercises are central to staff's efforts to develop its technical assessment capability efforts. Because knowledge of the repository system is incomplete, it is quite possible to arrive at multiple interpretations of what information is available. This can readily lead to alternative and conflicting conclusions about repository performance. IPA provides the NRC staff its only vehicle to develop independently the requisite understanding of the integrated repository system and, as such, permits staff to critically evaluate DOE's interpretation(s) of the site information, as well as to explore the impact of the staff's own interpretation(s) on repository performance.

NRC's first IPA exercise, IPA Phase 1, was completed in 1991 and was published as NUREG-1327. It was undertaken primarily to demonstrate NRC's ability to conduct a PA analysis and relied on very limited Yucca Mountain-related data, employed numerous simplifying assumptions, and evaluated only a small number of scenarios. The analysis produced a quantitative estimation of total-system performance, using available mathematical models and computer codes supplemented by a number of auxiliary analyses that supported and evaluated assumptions invoked in the total-system calculations. The focus of the calculations was the total-system performance measure as stipulated in the containment requirements of 40 CFR Part 191, as published by EPA in 1985. Virtually every aspect of the staff's HLW PA methodology developed for NRC at Sandia National Laboratories was exercised, including uncertainty and

sensitivity analyses. Uncertainty analysis was used to quantify the uncertainty in the performance measure caused by the uncertainty in the input parameters and in the future states that the disposal system could attain. The results of the analysis were used to construct the CCDF of total radionuclide discharges to the accessible environment over the 10,000-year regulatory period, as prescribed in the EPA standard. Sensitivity analysis was performed to identify those input parameters with the largest relative influence on the estimated performance measure and provided some insights regarding data needs and their relative priorities. By conducting IPA Phase 1, NRC was able to demonstrate its independent staff capability to: conduct PA analyses; evaluate the adequacy of existing tools and assess the need to further enhance these tools; and, most importantly, establish a basis for preliminary judgments regarding data needs and their respective priorities for DOE's SCP.

IPA Phase 2 used the same basic approach as Phase 1, but included significant enhancements as a result of implementing preliminary conclusions of Phase 1. These enhancements included: (1) use of a largely automated total-system code; (2) inclusion of a dose assessment capability; (3) evaluation of the SNL scenario-selection methodology; (4) analysis of a larger number of scenarios; (5) improved modeling of groundwater flow and radionuclide transport processes in unsaturated, fractured rock; (6) inclusion of a gaseous transport pathway; (7) inclusion of radionuclide transport in the saturated zone; (8) improved treatment of the radionuclide source term; (9) incorporation of additional methods for uncertainty analysis and sensitivity analysis; and (10) increased spatial resolution of the source term and transport modeling analyses.

The conduct of IPA Phase 2 has better prepared NRC to evaluate DOE Total System Performance Assessments and to engage in pre-licensing consultations with DOE on specific technical issues of importance to repository performance for which data are lacking. Applying the total-system code provided significant insights to NRC about the importance of the interactions between different components. Although the model for each one of these components can be exercised independently, the components of a repository system can interact in a complex fashion, and those interactions could have only been captured and examined in the context of the total-system code. As a result, NRC is now able to evaluate more meaningfully the assumptions made by DOE and to emphasize to DOE those issues of importance to safety. For example, this ability to incorporate more scenario classes and other potentially important radionuclide transport pathways (e.g., gas-phase transport) affords NRC increased flexibility to explore alternative interpretations and formulations of the repository system and assess their impact on repository performance. The results of Phase 2 allowed NRC, given the assumptions made in the analysis and the large data uncertainties, to identify the dominant radionuclides contributing to releases to the accessible environment, the primary pathways contributing to dose to man, and the effect of specific scenarios such as climate change and magmatism. Sensitivity analyses confirm staff's view that corrosion of the waste canister and infiltration are important processes that need to be more carefully investigated.

A necessary complement to IPA is the development and refinement of mathematical models and codes that assist the staff in establishing a sound

conceptual understanding of phenomena critical to the long-term performance of the repository system and their impact on estimates of relevant performance measures. Among these are the interactions between the natural and engineered components of the disposal system and their responses to changes in the environment; the causal relationships between the controlling physical and chemical processes; and the nature and propagation of uncertainties associated with these processes.

For example, risks associated with igneous activity are of considerable concern to the staff. Initial efforts to address the risks attributable to volcanism were incorporated into IPA Phase 2. However, staff analyses regarding probability derivations for future volcanism have shown that, for the Yucca Mountain region, the distribution of volcanic centers may not adequately be described by a homogeneous Poisson model that is favored by DOE. As a result, such derivations may not be adequate, as currently conducted. Additionally, modeling of the consequences resulting from volcanism conducted by DOE, to date, does not appear to appropriately incorporate all relevant processes and factors (e.g., the percentage of volatiles in the parent magma). The staff intends to explore the use of other models, for volcanic risk, in attempts to provide a technically-defensible approach for evaluating the risks and effect of volcanism on assessments of overall system performance.

In addition to developing greater understanding of the geologic and seismic phenomena affecting the repository, modeling and code development activities are underway to enhance staff's capability to assess the performance of the repository's geochemical, hydrological, and engineered barrier systems, as well. The experience gained from this model and code development is applied directly to the evolution of staff's IPA system code and provides a working platform from which staff can evaluate DOE's concepts and models.

5. GENERAL SUPPORT OF NRC's HLW REGULATORY PROGRAM

NRC's PA program also contributes to the overall HLW regulatory program in several general areas, such as providing support to NRC participation in international HLW activities, briefing the Advisory Committee on Nuclear Waste (ACNW), and supplying a basis for the preparation of research user needs.

The development of PA methodologies, and associated tools, procedures, and methods is vigorously being pursued in a number of other countries with ongoing geologic repository programs. NRC has a number of bi- and multi-lateral agreements with organizations participating in the HLW program in several of these countries. In addition, NRC actively participates in many activities, related to PA sponsored by the Organization for Economic Cooperation and Development's Nuclear Energy Agency (NEA). Participation in these international activities is motivated by the need to: stay abreast of new developments, obtain broad-based peer review of NRC's PA program and activities and leverage available resources by participating in activities of interest to NRC. At present, NRC is participating in six major international activities: (1) NEA's Performance Assessment Advisory Group; (2) NEA's Probabilistic Safety Assessment Group; (3) INTRAVAL model validation exercise; (4) NRC/SKI model validation study; (5) BIOMOVS, a biosphere exposure pathways modeling study; and (6) DECOVALEX, a coupled thermo-mechanical-hydrologic

validation study. The NRC staff strongly believes that frequent and visible participation in internationally-respected PA activities is important to maintaining NRC's credibility.

The NRC staff briefs the ACNW on select PA topics of interest to the committee, as well as, on the staff's overall PA capabilities and activities. NRC and the CNWRA staff participated in an all-day briefing of the ACNW on May 16, 1994, on the subject of NRC staff's capabilities in computer modeling and PA for the HLW regulatory program. In addition, results of IPA Phase 2, specific to thermal effects, have been presented to the Nuclear Waste Technical Review Board, at its request.

NRC's HLW research activities, conducted in coordination with the NRC Office of Nuclear Regulatory Research and the CNWRA, are supported, consistent with the Agency's licensing role and responsibilities. The focus of these research projects is: the development of the tools and technical bases necessary to judge the adequacy of DOE's license application; assurance of sufficient independent understanding of the basic physical processes taking place at the geologic repository; and maintenance of sufficient confirmatory research capability. The specific research projects are initiated on the basis of user needs identified by the Office of Nuclear Material Safety and Safeguards staff, and their respective priorities guided, in significant measure, by the needs identified by the staff's PA experience.