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APR 1 4 1994

MEMORANDUM FOR: The Chairman
Commissioner Rogers
Commissioner Remick
Commissioner de Planque

FROM: James M. Taylor
Executive Director for Operations

SUBJECT: THIRD AND FOURTH MEETINGS OF THE NATIONAL ACADEMY OF SCIENCES' COMMITTEE ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS, NOVEMBER 9-10, AND DECEMBER 16-17, 1993

On November 9-10, and December 16-17, 1993, the National Academy of Sciences (NAS) Committee on Technical Bases for Yucca Mountain Standards held its third and fourth open meetings in Las Vegas, Nevada, and Washington, D.C., respectively. The Nuclear Regulatory Commission was represented at both of these meetings by the NRC liaison to the committee and other staff of the Division of High-Level Waste Management. NRC was also represented at the December meeting by the Director of the Office of Nuclear Material Safety and Safeguards and by a member of Commissioner Rogers' staff. Meeting agenda and summaries of the presentations, ensuing discussion and questions raised by the committee are provided as Enclosures 1-4.

NOVEMBER MEETING: PROBABILITY AND CONSEQUENCES OF REPOSITORY DISRUPTIONS

This meeting was devoted to a discussion of the assessment of the probability and consequences of repository disruption and was the second of three meetings to review the state of scientific understanding of various questions before the committee. Expert presenters from national laboratories, universities, industry, and government agencies spoke on topics including: the geology of the Yucca Mountain region; potential disruptions of repository performance (because of volcanism, earthquakes, human intrusion); prevention of human intrusion, using active and passive controls; and treatment of uncertainty. At the committee's request, Dr. Norman Eisenberg, Section Leader of the Performance Assessment Section, presented an overview of NRC staff analyses of the potential impacts of human intrusion by drilling into the repository. These analyses were performed as a part of Phase 2 Iterative Performance Assessment activities.

During the discussion, the committee also expressed interest in a number of related issues, including: the role of expert judgment in performance assessment; how institutional controls could be implemented in the standard (e.g., extent of reliance and effectiveness, whether they should be required, and how they might be integrated with performance

assessment); how to fashion an appropriate standard that applies to a single site; how to address factors that cannot be rigorously quantified; and whether the committee is at liberty to address waste management solutions other than geologic disposal.

DECEMBER MEETING: PERFORMANCE OF AN UNDISTURBED REPOSITORY

The third and final meeting to review the state of scientific understanding of various questions before the committee was devoted to discussions of the assessment of the performance of an undisturbed repository. Presentations included: an overview of the groundwater hydrology at the site; modeling of the engineered barrier system; the influence of thermal effects on radionuclide transport; radionuclide transport through the geologic system; and the system models used to assess the performance of the repository. At the committee's request, Mr. Robert Bernero, Director of the Office of Nuclear Material Safety and Safeguards, gave a presentation on the role of performance assessment in licensing the disposal of high-level waste. A copy of Mr. Bernero's prepared remarks are provided as Enclosure 5.

Follow-up Activity

The committee held a closed meeting in February. At the request of both the U.S. Department of Energy (DOE) and Nye County, Nevada, a portion of the April meeting will be reserved for open session. Representatives of DOE, Nye County, and other interested parties will be afforded the opportunity to submit written statements to this session, at which committee members may question them on the content of their submitted statements. No oral presentations are scheduled. The NRC staff has been invited to attend the open portion of the April meeting and has agreed to be available to answer any questions with regard to prior NRC staff positions presented to the committee. In June 1994, the committee has scheduled a closed writing session and expects to issue its formal, peer reviewed recommendations by December 1994.

At the request of the NRC staff, the Center for Nuclear Waste Regulatory Analyses (CNWRA) conducted a comprehensive review of the regulatory bases of the positions taken by the NRC staff on specific issues relevant to the health basis of the Standard. The CNWRA report was submitted in November 1993. The NRC staff's review of the report and subsequent discussions between NRC staff and CNWRA staff did not identify any significant omissions, or any errors in logic, in the positions taken by NRC staff and articulated to the committee at the May 1993 meeting. The NRC staff will

continue to provide information, as requested by the committee, consistent with the Commission's previous positions on these issues and will raise to the Commission's attention any new matters of policy.

Original signed by
James M. Taylor

James M. Taylor
Executive Director
for Operations

Enclosures:
1. November Meeting Agenda
2. December Meeting Agenda
3. Presentation Summary of November Meeting
4. Presentation Summary of December Meeting
5. Prepared Remarks of R.M. Bernero on Use of Performance Assessment

cc: SECY
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*SEE PREVIOUS CONCURRENCE

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NAME	JRFirth/cj	JPKotra	MVFederline	BJYoungblood
DATE	04/01/94	04/01/94	04/01/94	04/01/94

OFC	NMSS	NMSS	EDO	EDO
NAME	GArlotto	RMBernero	HThompson	JMTaylor
DATE	04/1/94	04/1/94	04/13/94	04/14/94

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James M. Taylor
Executive Director for Operations

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NAME	GArlotto		RMBernero		HThompson		JMTaylor	
DATE	03/ /94		03/ /94		03/ /94		03/ /94	

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NATIONAL RESEARCH COUNCIL
COMMISSION ON GEOSCIENCES, ENVIRONMENT, AND RESOURCES
2101 Constitution Avenue Washington, D.C. 20418

BOARD ON
RADIOACTIVE WASTE MANAGEMENT
(202) 334-3066 Fax: 334-3077

Office Location:
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Room 456
2001 Wisconsin Avenue, N.W. 20007

FINAL AGENDA
COMMITTEE ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS

Howard-Johnson Plaza Suite Hotel
4255 South Paradise Road
Ballroom A
Las Vegas, Nevada

Third Meeting
November 9-10, 1993

Tuesday, November 9

9:00 am OPENING REMARKS

Bob Fri, Committee Chairman
- Purpose of meeting
- Approval of agenda
- Format of discussions

9:15 am OVERVIEW OF YUCCA MOUNTAIN GEOLOGY

speaker: Burt Slemmons (consulting geologist)
Copies of visual aids for the presentation entitled, "Overview of Yucca Mountain Geology" were distributed. Also, the following documents were distributed: "General Description of the Geology at Nevada Test Site", "The Decade of North American Geology: 1983 Geologic Time Scale", and "Major Stratigraphic Units in the Yucca Mountain Region"

discussant: Patricia Cashman (University of Nevada, Reno)
Copies of visual aids for the presentation entitled, "Hydrocarbon Resource Potential" were distributed.

discussant: Donald Noble (University of Nevada, Reno)
Copies of visual aids for the presentation entitled, "Mineral Resources and Potential and Related Human Interference at Yucca Mountain" were distributed.

ENCLOSURE 1

10:30 am DISRUPTION IN REPOSITORY PERFORMANCE DUE TO VULCANISM: PROBABILITIES AND EFFECTS

speaker: Bruce Crowe (Los Alamos National Laboratory)
Copies of visual aids for the presentation entitled, "Volcanism Studies" were distributed. Also, copies of the document, "Simulation Modeling of the Probability of Magnetic Disruption of the Potential Yucca Mountain Site" were distributed.

speaker: Michael Sheridan (SUNY Buffalo)
Copies of visual aids for the presentation entitled, "A Risk-Based Analysis of Volcanic Impact at Yucca Mountain" were distributed.

discussant: Eugene Smith (University of Nevada, Las Vegas)
Copies of visual aids for the presentation entitled, "The Importance of Regional Structures in Volcanic Hazard Assessment" were distributed.

discussant: Chih-Hsiang Ho (University of Nevada, Las Vegas)
Copies of visual aids for the presentation entitled, "Sensitivity in Risk Assessment for the Yucca Mountain High-Level Nuclear Waste Repository Site: The Model and the Data" were distributed.

12:30 pm Lunch

1:45 pm PREVENTING HUMAN INTRUSION USING ACTIVE AND PASSIVE CONTROLS

speaker: Tim Margulies (US Environmental Protection Agency)
Copies of visual aids for the presentation entitled, "Preventing Human Intrusion Using Active and Passive Controls" were distributed.

speaker: Abe Weitzberg (NUS Corp)
Copies of visual aids for the presentation entitled, "Reducing the Likelihood of Future Human Activities That Could Affect Geologic High-Level Waste Repositories" were distributed.

speaker: David Givens (American Anthropological Association)
Copies of visual aids for the presentation entitled, "Long-Range Changes In Human Society" were distributed.

4:15 pm EXECUTIVE SESSION

Wednesday, November 10

8:30 am DISRUPTION IN REPOSITORY PERFORMANCE DUE TO EARTHQUAKES: PROBABILITIES AND EFFECTS

speaker: Kevin Coppersmith (GEOMATRIX)
Copies of visual aids for the presentation entitled, "Preliminary Assessment of Fault Rupture Hazard at the Yucca Mountain Site Based on Expert Judgment" were distributed. Also, the document entitled, "Earthquakes and Tectonics Expert Judgment Elicitation Project" was distributed.

speaker: Anne Kiremidjian (Stanford University)
Copies of visual aids for the presentation entitled, "Disruption in Repository Performance Due to Earthquake Events: Probabilities and Effects" were distributed.

discussant: Steve Wesnouski (University of Nevada, Reno)
Copies of the following documents were distributed: "Quaternary Fault Interconnection and Possible Distributive Behavior at Yucca Mountain, Southern Nevada" and "Distributed Surface Faulting from the 1932 Cedar Mountain Earthquake, West-Central Nevada: Seismic Hazard Implications for the Basin and Range Province"

10:15 am DISRUPTION IN REPOSITORY PERFORMANCE DUE TO HUMAN INTRUSION: PROBABILITIES AND EFFECTS

speaker: Tim Margulies (US EPA)
Copies of visual aids for the presentation entitled, "Disruption in Repository Performance Human Intrusion: Probabilities and Effects" were distributed.

speaker: Norman Eisenberg (US Nuclear Regulatory Commission)
Copies of visual aids for the presentation entitled, "Analysis of Human Intrusion: Drilling Models for NRC's Iterative Performance Assessment Capability" were distributed.

speaker: Detlof Von Winterfeldt (University of California, Los Angeles)
Oral remarks only

12:00 noon Lunch

1:15 pm DISRUPTION IN REPOSITORY PERFORMANCE DUE TO HUMAN INTRUSION: PROBABILITIES AND EFFECTS *(continued)*

speaker: Felton Bingham (Sandia National Laboratory)
Copies of visual aids for the presentation entitled, "Remarks on the Treatment of Human Intrusion in a Standard for the Disposal of High-Level Waste" were distributed.

speaker: Kai Erikson (Yale University)
Oral remarks only

2:45 pm DEALING WITH UNCERTAINTIES OF GEOLOGIC EVENTS, HUMAN INTRUSION, AND CONTROLS IN THE CONTEXT OF THE STANDARD

Committee discussion with previous speakers and discussants

4:15 pm Public Comment
Tom McGowan
Copies of written commentary were distributed.

Robin McGuire (Risk Engineering, Inc)
Copies of the figure entitled, "Sensitivity of CCDF for ^{237}Np to Earthquake Occurrences" were distributed.

Judy Triffle (Nevada Nuclear Waste Task Force)
Oral remarks only

4:45 pm Committee discussion of future plans

5:00 pm Adjourn

NATIONAL RESEARCH COUNCIL
COMMISSION ON GEOSCIENCES, ENVIRONMENT, AND RESOURCES
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Office Location:
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2001 Wisconsin Avenue, N.W. 20007

December 6, 1993

MEMORANDUM

To: Mailing List

From: Myron F. Uman and Ray Wassel MU RW

Subject: December 16-17 meeting of the NAS Committee on Technical Bases for Yucca Mountain Studies

The committee's meeting on December 16-17, 1993 will be held in Washington, DC at the Holiday Inn, Georgetown. The hotel is located at 2101 Wisconsin Avenue, NW, adjacent to offices of the National Research Council. The telephone number of the hotel is (202) 338-4600.

The main subject of this meeting will be the technical bases for assessing the performance of an undisturbed repository. In addition, one session will focus on the use of performance assessment and other technical analyses in regulatory decision making. A preliminary agenda is enclosed.

Once again, because this meeting will be held away from of our own conference facilities, we need to have a reasonably accurate estimate of attendance to be sure to have adequate space, enough chairs, and sufficient coffee. Therefore, we ask that you please let Lisa Clendening know if you plan to attend. Her fax number (preferred) is (202) 334-3077 and her telephone number is (202) 334-3066. Thanks.

Enclosure

cc: Committee members

NATIONAL RESEARCH COUNCIL

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COMMITTEE ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS

Holiday Inn
2101 Wisconsin Ave. NW
Washington, DC

PRELIMINARY AGENDA FOR FOURTH MEETING
December 16-17, 1993

All sessions are open to the public except as noted.

Thursday, December 16

8:30 am — Introductions and Opening Remarks
Bob Fri, Committee Chairman

Part I. State of Knowledge Regarding Performance Assessment for an Undisturbed Repository

8:45 am — Overview
Jerry Boak (DOE)

Engineered Barrier System

9:30 am — Waste Form, Waste Container, Thermal Loading
David Stahl (B & W Fuel Co.)

Thermal Loading
Don Shettel (Geosciences Management Institute)

Waste Container Performance
Roger Staehle (University of Minnesota)

Predicting Releases from the Waste Container
Mick Apted (Intera Information Technologies)

12:00 noon — Lunch

1:00 pm — Thermal Effects and Radionuclide Transport
Tom Bushak (Lawrence Livermore National Lab)
Martin Mifflin (Mifflin & Associates)

Geologic System and Radionuclide Transport

2:30 pm — Saturated aqueous flow
Bill Dudley (USGS)

Unsaturated aqueous flow
Alan Flint (USGS)

Gas phase flow
Ed Weeks (USGS)

Sensitivity of flux rates to choice of hydrologic flow models
Linda Lehman (L. Lehman & Associates)

5:00 pm — Executive Session (closed to the public)

Friday, December 17

Part I. State of Knowledge Regarding Performance Assessment for an Undisturbed Repository (continued)

9:00 am System models
Suresh Pahwa (Intera)
Robin McGuire (Risk Engineering, Inc)

Part II. Releases to Dose and Risk, revisited

10:15 am Graham Smith (UK Intera Information Technologies)

Part III. Health-Based Standard: Additional Considerations

11:00 am Alternative Considerations for the Standard
Graham Smith (UK Intera Information Technologies)

12:00 noon Lunch

1:00 pm Using Technical Analyses in Regulatory Decision Making
Robert Bernero (US Nuclear Regulatory Commission)

2:00 pm Comments from the public

3:00 pm Planning for future meetings

3:30 pm Adjourn

THIRD MEETING OF THE COMMITTEE ON TECHNICAL BASES
FOR YUCCA MOUNTAIN STANDARDS

THIRD MEETING

NOVEMBER 9-10, 1993

ENCLOSURE 3

THIRD MEETING OF THE COMMITTEE ON TECHNICAL BASES FOR
YUCCA MOUNTAIN STANDARDS
November 9-10, 1993

PRESENTATION SUMMARY

SESSION I: OVERVIEW OF YUCCA MOUNTAIN GEOLOGY

This session presented an overview of the major geological elements in the Great Basin Region and the Yucca Mountain vicinity. The major topics covered were stratigraphy, faulting, mineralization, and the potential for resource exploration and exploitation.

B. Slemmons (Consulting Geologist, Woodward-Clyde Federal Services) presented a broad overview of the geologic structures of the Great Basin region. He discussed the plate tectonic relationships with the region's gross geologic features. Stratigraphy, folding, mineralization, and the potential for hydrocarbon concentration have all been influenced by the collision between the Pacific and North American plates. Changes in stress relationships have produced the extensive surface faulting and volcanism observed in the region. Because of its geologic history, the region surrounding Yucca Mountain is characterized by an extremely complex pattern of faulting. Before 7 million years ago, this region was far more tectonically active and subsequent activity appears to be decreasing. Between 6 and 17 million years ago was also a period of extensive volcanic activity dominated by the Timber Mountain Caldera, north and east of the Yucca Mountain site.

The nature of faulting in the immediate Yucca Mountain vicinity is a matter of concern to the repository project. Although a somewhat regular pattern of NNE faults dominates the northern portion of the site, faulting elsewhere at the site is much more heterogeneous. Although faults known to have been active within the last 1 to 2 million years have been identified to the east and west of Yucca Mountain, their recurrence intervals are measured in the tens of thousands to hundreds of thousands of years. Less clear is the recent tectonic activity of the Ghost Dance Fault that runs directly through the repository block, but no conclusive evidence of Quaternary activity has, of yet, been obtained. At least two conflicting tectonic models have been advanced to explain the complex pattern of faulting observed, which has led to very different assessments of the potential for fault activity. The U.S. Geological Survey (USGS) is conducting extensive work to further characterize the faulting in and around the site.

According to Slemmons, future development or exploration for groundwater resources is at least as likely to occur as future prospecting for mineral or hydrocarbon resources. Known resources near the site include major deep carbonate aquifers southeast of the site, and shallow volcanic and possible deep carbonate aquifers beneath the site.

P. Cashman (University of Nevada, Reno) discussed the hydrocarbon resource potential and the potential for exploration in the Yucca Mountain region. Factors necessary for hydrocarbon generation and accumulation (i.e., source rock, maturation, reservoir rock, and traps) were discussed. According to

Cashman, the stratigraphy of the region is clearly amenable to hydrocarbon formation. She noted that the fold belt running through the Rocky Mountains has proven to be a major source of hydrocarbons. Known hydrocarbon fields in Nevada occur almost exclusively in valleys and not within ranges. Reservoir rock and primary source deposits exist, however, throughout the Nevada Test Site (NTS) and at Yucca Mountain. Cashman indicated that it is possible for a tuff site (such as Yucca Mountain) to contain a hydrocarbon reservoir above the valley floor and cited some limited historical evidence of drilling at heights elsewhere in the region. These factors might indicate that the area around Yucca Mountain could be prone to exploration for hydrocarbons, but that drilling would predominantly occur in the surrounding valleys. Cashman then discussed the history of resource exploration, indicating that, while, historically, Nevada has shown a lower success rate (1.9 percent) than the national average (10 percent); successful wells found in Nevada have tended to be extraordinarily productive. Promising indicators (or "shows") have been detected at 13 of 24 wells drilled closest to the site. Historical evidence also suggests that a large number of test wells have been drilled before and between discoveries of commercially viable wells. The speaker volunteered that, based on the historical record, she is far more confident of her ability to estimate the probability that hydrocarbon reserves actually exist in or around Yucca Mountain than she is the probability that people might drill there.

D. Noble (University of Nevada, Reno) presented a case that Nevada is rich in valuable minerals and that mineral exploitation should be considered as a realistic possibility at Yucca Mountain. Gold is the most important mineral found in the area, and producing mines have been located within 25 miles of Yucca Mountain. Because of the many areas of hydrothermal alteration surrounding Yucca Mountain, as well as evidence that solutions of the type that deposit gold have been present in the repository region, Noble believes there is a significant potential for mineralization beneath Yucca Mountain. Planned site characterization activities will be insufficient, in his view, to properly characterize the resource potential or to rule out deposits at depth. Noble also cautioned that the presence of known ore deposits around Yucca Mountain and evidence of underground excavation that will inevitably persist after closure of a repository could themselves attract future prospecting.

The committee asked a number of questions related to unique features and resource potential of the Yucca Mountain site, and the technical considerations that should be addressed in developing the standard. Important issues that should be considered in the formulation of a standard were identified by the presenters. Among them were: the probability of fault occurrence vs. probability of disruption (Slemmons); features that indicate mineralization (Noble); mineralogical and hydrocarbon potential at the site (Noble, Cashman); increasing trends in drilling rates (Cashman); and the difficulty in determining where, or how, exploration will occur (Cashman, Noble).

SESSION II: DISRUPTION IN REPOSITORY PERFORMANCE DUE TO VOLCANISM: PROBABILITIES AND EFFECTS

This session concerned the challenges associated with developing acceptable models of volcanic risk and incorporating them in repository performance assessments. Major topics included: contributors to uncertainty; the effect of regional structures on volcanism; and acceptable choices of models and parameters.

B. Crowe (Los Alamos National Laboratory) asserted that the key issue is how to bound uncertainty in the estimate of risk related to volcanism. He asserted that a probabilistic approach is the only logical means. Although it is not possible to predict a particular volcanic event, it is possible, in his view, to bound the risk of events of a given magnitude. Crowe suggested that the sparseness of the volcanic data base at Yucca Mountain underscores what he terms the "data paradox," or the fact that sites where the geologic record provides sufficient evidence of volcanic events for statistically robust data are too active to be considered for high-level waste (HLW) disposal at all. Conversely, the statistically poor data base for Yucca Mountain is a direct result of the low probability of volcanic events at the site. As it is unlikely that any new evidence of previously unrecognized volcanic events will be uncovered, uncertainty will persist, and the issue is how, given limited event data, to bound the residual uncertainty. Crowe stated that existing data suggest a waning system and that the steady state assumptions employed in most probability estimates may well be overly conservative. Crowe also commented that existing regulations (especially NRC's) are vague on how to apply probabilistic risk assessment to events with low probabilities over very large time scales. This leaves the door open, in his view, for the regulator or others to indulge in a propagation of worst-case assumptions in order to achieve "reasonable assurance." This, in turn, can lead to calculations that correspond to physically impossible or unreasonable scenario descriptions.

M. Sheridan (State University of New York at Buffalo, working in association with Electric Power Research Institute (EPRI)) discussed the application of volcanic risk studies to Yucca Mountain. He indicated that risk assessment must be integrated with other methods, and that this should proceed by: (1) establishing criteria for the acceptance of models and parameters; (2) developing conceptual models that fit the established criteria; (3) determining the probability functions for the appropriate processes; (4) assessing and reducing the uncertainties within the data set; and (5) refining the conceptual model. It was suggested that a logic tree approach to develop the conceptual models is warranted. This would allow the use of expert judgment considering diverse data, the incorporation of a wide range of perspectives, and feedback into the models during refinement. Sheridan urged that studies of the eruptive probability at Yucca Mountain be expanded to include the larger community of scientists expert in the assessment of global volcanic risks and not to limit the debate to volcanologists who specialize in the volcanic history of the local region. He asserted that current differences related to the estimate of the probability of volcanism at Yucca Mountain stem from differences in definitions. He recommended that a series of workshops implementing the process that he proposed would facilitate assignment of probabilities.

E. Smith (University of Nevada, Las Vegas) took serious exception to the first two presentations, arguing the importance of regional structures in the assessment of volcanic hazards. It was stated that the investigation of these hazards should be driven not by statistics, but by relevant geologic features. Smith offered that volcanoes tend to form chains parallel to regional structures, and that in the vicinity of Yucca Mountain, the most recent volcanic chains are controlled by North-Northeast trending faults and structures. Smith contends that appreciation of this structural control leads to significantly higher estimates of eruptive probability at Yucca Mountain.

C. Ho (University of Nevada, Las Vegas) discussed at length the sensitivity of predictions of eruptive probabilities to key statistical modeling assumptions (e.g., use of simple Poisson vs. Weibull process models). Ho stated that his analyses of instantaneous recurrence rates imply that volcanism at Yucca Mountain is increasing. He also indicated that the inclusion of a potential, but as of yet unconfirmed, recent volcanic event at Lathrop Wells would significantly increase the volcanic risk estimate for the site.

B. Crowe objected to the presentations of Smith and Ho, arguing that the data set is too small to prove either northeast or northwest trending in volcanic activity or, for that matter, to support any detailed, site-specific fine structure in assessing volcanic activity at Yucca Mountain. He stressed the large uncertainty in the calculations and asserted that Ho had introduced a bias into his treatment of the existing data, using a combination of worst-case assumptions that is not physically possible. Crowe also asserted that there is no getting around the fact that the volcanic data will remain limited even after site characterization is complete. In Crowe's opinion, the real questions that should be of interest to the NAS committee are how to select a reasonable distribution or range of probabilities and what point in the range will suffice for regulatory decision-making.

In response to a committee question as to whether more field data would resolve these differences, Smith stated that the proper geochemical studies could go a long way to further define the numbers and groupings of volcanic events. He also suggested that studies of volcanism at Yucca Mountain have not yet "reached the state-of-the-art," and that more robust calculations are possible with better data.

S. Wiltshire questioned whether, for purposes of recommending a standard, they (members of the committee) were obligated to consider only those things that are currently able to be demonstrated. C. Whipple cautioned that the standard should not ask for proof that can never be provided and that the committee's job was to make the hard judgment call in deciding how the standard should be formulated such that it doesn't ask for unknowable things. There was also discussion on the degree of certainty that can be required and the use of end-points or distributions in the regulations. One committee member asserted that selecting the end points of a distribution as a standard is not workable.

SESSION III: PREVENTING HUMAN INTRUSION USING ACTIVE AND PASSIVE CONTROLS

This session covered various aspects of institutional control. The major topics discussed were: differences between active and passive controls, the

effectiveness and duration of the controls, different options for establishing passive control, and how changes in human society could influence the success of messages used to convey information about the repository to future generations.

T. Margulies (U.S. Environmental Protection Agency (EPA)) discussed the differences between active and passive institutional controls. EPA's definition of passive controls includes the following: permanent markers, public records and archives, government ownership, regulations on the use of land or resources, and other methods of preserving knowledge about the disposal system. Active controls are those means used to control access to the site in ways other than through passive controls such as maintenance and remedial actions, controlling or cleaning up releases, and monitoring parameters related to the performance of the disposal system. EPA believes that passive controls are more likely to be effective for longer periods than active controls. Margulies acknowledged that use of passive institutional controls should reduce the likelihood of inadvertent intrusion relative to the case where no markers or records were in place, but would not suggest any acceptable "credit" for their presumed effectiveness. Margulies suggested that relative comparisons of the effectiveness of controls, passive or active, could be expected to be more reliable than absolute performance predictions. He suggested that implementing agencies are free to use their own assumptions if they develop information adequate to support those judgments.

A. Weitzberg (NUS Corporation) presented the results of the Human Interference Task Force Study (1980-1982) and described the assumptions made in the study. The Task Force identified actions that can deter human interference, among them: initial selection of a suitably unattractive site taking into account resources, natural features, and land usage during siting; repository design that incorporates site-specific features, to prevent interference; and development of durable messages about the content and risks of the closed repository. Examples of different marker concepts were presented, and the effectiveness of different types of controls was discussed. These include: oral transmission, maps, markers, monuments, earthworks, and archives. The conclusions of the task force were that: there would be a high probability of the survival of permanent markers and monuments; site-specific knowledge (on-site, off-site, verbal, and written) would be retained; society would periodically refurbish or update message channels; and the likelihood of significant inadvertent interference is relatively remote. The refurbishing or updating of passive controls at periodic intervals was termed a "relay system," which was thought to increase the length of time over which these controls would be effective.

D. Givens (Analytic Futures and Forecasts) discussed the impact of long-range changes in human society on the success of messages to future generations about the repository. The changes in human society were traced by looking at five points in time ranging from 10,000 years in the past to 10,000 years in the future. The difficulty in finding a message (even when it is available and can be interpreted) is a challenge that exists today and should be assumed to be a problem for future societies. The potential for future "dark ages" was discussed as an argument against relying on institutional control. Givens indicated that one of the more likely scenarios of intrusion might be future

archaeologists who may wish to excavate the site to learn about the past. He concluded that active institutional controls cannot, alone, guarantee that intrusion will not occur.

The committee expressed interest in EPA's choice of 100 years as the limit used for the period of active institutional controls and in the EPA definition of "reasonable." S. Burstein took exception to statements that the use of controls will not guarantee protection from inadvertent intrusion, indicating that, in this context, absolute guarantees are neither expected nor required. The committee questioned the success of historical monuments and markers, whether the long-term persistence of the other available options (i.e., storage) had been considered for comparison, and the timeframe for the endurance of monuments and other types of passive controls. Wiltshire commented that markers and monuments that we have today are only those that have persisted, and may not necessarily be representative of the endurance of markers generally. Givens suggested that the more robust markers would be in the forms of large-scale monuments, dielectric sands to mark for radar, pictographic messages, and monoliths. Weitzberg indicated that the costs for passive institutional controls would be negligible, since the institutions already exist. He also stated that as much as possible, within cost constraints, should be done. He later asserted that local populations, who have the most immediate interest in the security of the site, will act vigorously, to protect their own safety, by preventing intrusion. This was later disputed by S. Frishman (Nevada Nuclear Waste Project Office), who indicated that three nuclear weapons test sites at NTS are unmarked. He noted that the local population has not taken action to protect itself from these hazards.

Members of the committee questioned whether the standard should include a requirement for controls and whether estimates of risk attenuation achieved by these controls should be included in the performance assessment. Givens indicated that it would be possible only to make qualitative judgments. Weitzberg believed that you could get quantitative estimates for periods less than 500 years and that credit could be given for a reduction in risk. J. Bahr also asked what should be required in the licensing procedure. Whipple commented that the committee needs to come to grips with a definition of "unreasonable risk," to respond to the directive of Congress. Margulies provided three options for addressing human intrusion: assume human intrusion will occur and rely upon best available technology (BAT); assess human intrusion as part of performance assessment; or treat it outside of the performance assessment.

The committee asked for the speakers' opinions on the question posed in the Energy Policy Act of 1992 "...whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits." The opinions ranged from: it is reasonable only for very short periods (Margulies); it is reasonable, but only for some period somewhat less than the full 10,000 years (Givens); and that such controls will successfully protect the public for the full regulatory period (Weitzberg).

SESSION IV: DISRUPTION IN REPOSITORY PERFORMANCE DUE TO EARTHQUAKES: PROBABILITIES AND EFFECTS

This session was concerned with the modeling techniques and difficulties in performing risk assessments for earthquakes for the proposed repository. The major topics discussed included: the use of and role of expert judgment; advantages and disadvantages of probabilistic analyses; differences in results because of different models; the current status of modeling; the state of knowledge about seismic events; and the uncertainty in predicting future events.

K. Coppersmith (GEOMATRIX) presented the methodology and results of an EPRI study, "Earthquake and Tectonic Expert Judgment Elicitation Project," to demonstrate methods for the elicitation of expert judgment and to quantify uncertainties associated with earthquake and tectonic issues. He described EPRI's elicitation process and the logic tree approach employed to accommodate multiple tectonic models and to quantify uncertainty. The study addressed both primary displacement within the repository block itself, as well as secondary displacement. Results were reported as distributions of the probability of "canister failure," assuming a failure criterion of either a 1-cm (0.39 in) diameter breach or a 10-cm (3.94 in) displacement. The final distributions, incorporating the experts' estimates of uncertainty, varied over four orders of magnitude. It was found that, given the underlying assumptions of the study, secondary displacement effects were more significant than the primary displacements. Coppersmith indicated that the study found that use of different tectonic models contributed little to the observed variation in seismic hazard estimates. These estimates appear far more sensitive to the assumed slip rates and recurrence intervals. The speaker indicated that a value of 0.44 had been assigned to the probability that the Ghost Dance Fault is an active Quaternary fault. He also indicated that event clustering has been observed in low probability areas similar to Yucca Mountain. According to Coppersmith, such regions are "too quiet" to rely on the historical frequency of events alone, and that use of expert judgment to evaluate and interpret ambiguous geologic data is inevitable, if useful probability estimates are to be obtained.

A. Kiremidjian (Stanford University) described the various seismic hazards (fault rupture, ground shaking, liquefaction, landslides or rockslides, and changes in the water table elevation) that will need to be assessed at Yucca Mountain. She also compared the advantages and disadvantages of deterministic as opposed to probabilistic analyses of seismic potential. Deterministic assessments, according to Kiremidjian, are much simpler and generally result in a single value that is much easier to explain. They do not, however, account for uncertainties and their use frequently leads to overly conservative facility designs. Probabilistic approaches are more complex and harder for the public to understand. They do, however, account for randomness in nature, and the uncertainty of parameters, and can also form the basis for design constraints that are consistent with resource considerations. According to the speaker, assessments of seismic potential for relatively quiescent regions are critically dependent on whether individual events are

assumed to be independent of each other. It was indicated that the time, magnitude, and location of events may very well depend upon preceding events. Although it may be appropriate to make simplifying assumptions of time independence for events of magnitude less than 6.5, such an approach may seriously underpredict larger, more rare events. If, for example, the Ghost Dance Fault had a major event 10,000 years ago and the arrival frequency for events of that magnitude was on the same order, a simple Poisson distribution would seriously underpredict the likelihood of the next event.

Kiremidjian presented the following general recommendations for using seismic hazard analysis: a systems approach is needed to develop a global risk model; a logic tree approach should be incorporated; errors in simplified models are best assessed through comparison with more complex models; and expert opinion is best applied to identifying appropriate scenarios and providing ranges of parameter values, rather than assigning probabilities. Kiremidjian indicated that a systems approach could be applied to the formulation of regulations and the determination of compliance. Additional work to define the components of a systems approach is needed, however, which she estimated would require on the order of 3 to 5 years. When queried as to the impact of seismic events on underground excavations, she replied that unless the active fault goes right through the excavation, most earthquakes have little effect.

S. Wesnouski (University of Nevada, Reno) highlighted the lack of knowledge about seismic events and the difficulties in predicting future events. Even in much more seismically active and better studied areas, earthquakes do not always occur on previously identified seismogenic structures. In areas where there are far fewer earthquakes, such as the vicinity surrounding Yucca Mountain, much less is known and it is very much harder to assess frequencies. For example, according to Wesnouski, there is no accepted regional explanation for why the zone of seismicity encompassing Yucca Mountain exists. Furthermore, there is some evidence that past events have arrived in clusters and cannot be appropriately modeled using steady-state assumptions expressed as an annual frequency. Geochemical evidence, from volcanic ash found in fractures from recent quakes near Yucca Mountain, lend additional support to the view that events in the region have occurred as simultaneous, multiple, ruptures rather than as discrete events. Earthquake ruptures are more distributed in this region than are observed in California, and are of larger magnitude than might be expected, because of the length of the isolated faults.

The committee expressed interest in the use of expert judgment and the treatment of "outlier" opinions. Additional information on the EPRI elicitation process was requested. The committee was quite concerned that different studies of seismic hazard appear to use different definitions of system or canister "failure." The committee also appeared skeptical of the EPRI study's somewhat arbitrary assumption of 0.44 as the likelihood that the Ghost Dance Fault is active. Burstein emphasized the necessity, when evaluating the relevant seismic hazards, to distinguish between those affecting pre-closure activities and those of significance to post-closure performance. Bahr questioned the role of expert judgment in determining that secondary displacements would be more significant than the primary displacement events. C. Fairhurst brought up the need to examine

international studies that suggest that underground structures can be built safely in close proximity to faults.

SESSION V: DISRUPTION IN REPOSITORY PERFORMANCE DUE TO HUMAN INTRUSION: PROBABILITIES AND EFFECTS

This session looked at the treatment of human intrusion in the assessment of long-term repository performance. The major topics included: the probabilities of human intrusion events; consequences of drilling events; how human intrusion might be addressed in the future standards; how human intrusion has been addressed in Europe; and other issues arising from the literature survey being conducted for the NAS study.

T. Margulies (EPA) discussed different ways of modeling the probability of human intrusion into the repository through drilling. Several probability distributions and models were presented and use of the Markov model and event tree analyses were discussed. Expected values of drilling rates for different models were compared.

N. Eisenberg (NRC) presented the NRC efforts at modeling human intrusion activities in the context of performance assessment. The techniques used in the Phase 1 and Phase 2 analyses were presented and contrasted. Reasons for attempting to model human intrusion, the choice of drilling as the most credible intrusion mode, and a set of projected consequences from drilling were discussed. Sample calculations showing the relative dose to an individual downwind of the repository for single drilling events at specified times were described and the results were presented. The presentation concluded with a discussion of what had been learned during the first two iterations of the NRC performance assessment activities and the problem areas that persist in the modeling of the consequences of human intrusion. In addition to identifying the limitations on the ability of models to adequately accommodate the full range of potentially disruptive human activities, Eisenberg noted that, in general, robust repositories that effectively contain nuclides for longer periods of time will pose more serious consequences when disrupted than will repositories that provide less effective containment.

At the request of the committee, D. von Winterfeldt (University of California, Los Angeles) has been conducting an extensive literature survey and presented his findings and observations to date. This included a definition of human intrusion that is used in Europe; problems with predicting the state of future societies; and a review of possible modes of intrusion. He offered his impression that predictions of human activity and the states of future societies are entirely speculative beyond roughly 1000 years. He indicated, however, that the current limit of 100 years for the applicability of active institutional controls should be reexamined, as such controls represent the best opportunity to reduce the opportunity for intrusion. More attention, he believes, should be paid to improving the long-term effectiveness of institutional controls. He also noted that estimates of drilling probabilities are probably as good as can be developed, given their high degree of sensitivity to assumptions with respect to the future states of societal and technological advancement. Von Winterfeldt concluded with a discussion of the regulatory options and their ramifications. The options

ranged from the direct regulation of markers, through the regulation of consequences, and to the use of probabilistic scenarios. He suggested that it might be useful to regulate the decision-making process rather than the technologies.

The committee asked for von Winterfeldt's opinion as to "...whether it is reasonable to assume that a system for post-closure oversight of the repository can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers or increasing the exposure of individual members of the public to radiation beyond allowable limits," and whether active controls will work well when they are working. Von Winterfeldt indicated that, in his view, the use of active controls, in conjunction with passive controls, will work better than markers, alone.

SESSION VI: DEALING WITH UNCERTAINTIES OF GEOLOGIC EVENTS, HUMAN INTRUSION, AND CONTROLS IN THE CONTEXT OF THE STANDARD

This session addressed how human intrusion might be treated in the standard and the uncertainty associated with predictions of human intrusion. A number of regulatory options were presented to the committee, along with their respective advantages and disadvantages. The conclusions of the Nevada Technical Review Committee on the Yucca Mountain Socioeconomic Project report "*Nuclear Waste at the Millennium: The Human Dimension*," was also presented.

F. Bingham (Sandia National Laboratory) outlined several options for addressing human intrusion in a new standard, on the premise that the new standard will be risk-based and probabilistic. The speaker was careful to distinguish between those options that might be more scientifically supportable, but are not "regulatorily" supportable. The options presented were to: (1) exclude human intrusion from the standard; (2) treat human intrusion only by means of qualitative discussions, supported by calculations; (3) keep human intrusion within the full Complementary Cumulative Distribution Function (CCDF); and (4) leave human intrusion out of the full CCDF and make a separate CCDF for human intrusion. Bingham suggested that the committee advise EPA on the appropriate rigor that is necessary for demonstration of compliance with a standard for the proposed repository at Yucca Mountain. He also asked the committee to consider whether the purported EPA risk objective of 1000 deaths in 10,000 years is scientifically meaningful. He recommended that the committee examine how different formulations of a new standard might be distinguished as providing greater or lesser protection on a scientifically supportable basis. Burstein queried Bingham as to whether his options would be different for different regulatory time-frames. Bingham replied that selection of a different time period could influence the pro and con arguments, but not the options themselves. Bahr commented that 40 CFR Part 191 was neither health- nor risk-based, and noted that the committee is not bound to either the earlier form or the risk rationale developed for the previous standard.

K. Erikson (Yale University and member of the Technical Review Committee of the State of Nevada) addressed what might not be known, or even knowable, about the potential for human intrusion and its consequences. In his view,

insufficient attention has been paid to assessing the full range of potential human activity that could affect the site. It was asserted that, consistent with the present rate of technological evolution, climate modification, mechanical alteration of groundwater flow, and the reshaping of continents, should not be ruled out as conceivable scenarios. According to Erikson, discussions of human intrusion have inappropriately relied on the thought processes, technologies, and societal structures of the late 20th century. It was noted in Erikson's report that as recently as 100 years ago, there were no known uses for uranium. Postulated intrusion scenarios have focused on inadvertent intrusion, using boreholes and mining. Such techniques may not be the methods of choice for future societies. Furthermore, advertent intrusion has not been considered at all because there is no information on how it might come about. Use of monuments was discounted, since the messages associated with past monuments, some considerably younger than 10,000 years, remain obscure or have been lost altogether. Erikson argued that we are obligated to make projections as far as our present tools can legitimately take us; beyond is "unknown," not "uncertain." When specifically asked by the committee, Erikson offered that the questions posed in the Energy Policy Act of 1992 should be answered in the negative.

COMMITTEE DISCUSSION

A vigorous discussion between the committee members and some of the presenters completed this session. The discussions touched on: what to do about the unknowable, the form of the standard, and the options available to the committee. Some of the specific topics that were addressed include: the role of multiple barriers; use of an assumed probability of human intrusion and/or geologic events, so that only the consequences need be addressed; the use of "stylized" or prescribed calculations in compliance determinations; and site selection in the context of the committee's charge. Some members questioned the extent of the committee's obligations, were it to arrive at a judgment that geologic disposal is not the scientifically most sound approach for managing high-level wastes. The problems of addressing regulatory needs that may not be scientifically supportable, and the impact of waiting upon the state of scientific understanding to advance, were also discussed.

Whipple asked what the committee should do if it is not possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion over a period of 10,000 years. Erikson argued for a pause in the "rush" to build a repository in its present form. Bingham conceded that the probabilities of human intrusion are not known and supported a more qualitative treatment of human intrusion, such that quantitative projections of human intrusion would not serve as a "go/no go" test, and such analyses could instead provide insights into the consequences of human intrusion at a given site. Bingham flatly asserted that "reasonable assurance" should not mean assurance that every conceivable, bizarre scenario would not occur. Erikson disagreed and stated that even the bizarre deserves consideration. In Erikson's view, any projections of human activity beyond 50 years in the future are, by definition, bizarre.

No consensus emerged with regard to whether waiting would improve the state of

knowledge enough to change the nature of the problem. Burstein questioned whether the answers to the scientific questions would be any more answerable after a delay, with retrievable storage as an intermediate option. Whipple commented that there are many safe, short-term solutions, but the question is what to do over the long term--at some point the unknowable now will remain unknowable 100 years hence, so when do you know enough to decide?

The discussion then progressed to how the standards might address potential disruptive events. Frishman indicated that DOE should be required to examine all of the reasonable consequences of human intrusion into any proposed geologic repository. According to Frishman, the probability of human intrusion should be assumed to be 1.0. Bahr indicated that an assumed probability of 1.0 could be extended to geologic events, as well. F. Phillips said that even if you look only at the consequences, you do not get away from the need for a probabilistic assessment, to determine the level of the consequences. Whipple commented that, in his view, the question should be whether the site responds "gracefully" to minor intrusions, recognizing that no site is immune from all conceivable intrusion scenarios, and that the overall probability of intrusion is best dealt with during site selection.

The debate also touched upon the process of site selection and the choice, by Congress, to proceed with the geologic disposal of high-level waste. The role of subsystem performance criteria in 10 CFR Part 60 was also raised. R. Budnitz commented that it was Congress that decided that the national policy is to pursue deep geologic disposal of high-level waste, and that Yucca Mountain was to be studied to determine whether it is a suitable site. The question before the committee, Budnitz continued, is: By what yardstick should the adequacy of Yucca Mountain be measured? A standard that no site could pass or no site could fail is no standard, in Budnitz' view. M. Carter commented that the implication [of the Congressional decision] is not that Yucca Mountain must be found to be the "best" or "safest" site, only that it be found adequately protective.

The committee Chairman, along with members Whipple, Bahr, and Budnitz noted, that there are aspects of the existing disposal standard that are related primarily to site selection. The relevance or utility of these aspects are not apparent, given that only one site is currently being characterized. It was debated whether the standard should focus solely on health- and/or risk-based criteria, or whether it should attempt to force engineering development or to compel DOE to do things differently. Budnitz indicated that the committee should not ignore the role and impact of NRC requirements and disagreed with the philosophy that engineering should not be used to compensate for a poor site. Whipple said that if the committee as a whole, decides that Congress was wrong in its decisions to pursue geologic disposal and to characterize Yucca Mountain, then the committee has the obligation to tell Congress. The Chairman reminded the committee members that they had earlier agreed that their role was to help EPA understand the technical basis for writing a standard for Yucca Mountain, that their job was not to write the standard or to tell EPA what "the number" should be.

PUBLIC COMMENTS

T. McGowan (citizen, no affiliation) believed that a broader public consensus needs to be brought into the process. R. McGuire (Risk Engineering, Inc.) noted that a systems approach to handle seismic hazards is currently available. He indicated that confidence in its application will grow as it is used for multiple applications. J. Triffle (Nevada Nuclear Waste Task Force) indicated that a standard specific to Yucca Mountain is very worrisome to Nevadans and urged the committee to assume that a human intrusion will occur, and focus on evaluating the consequences. In her view, people will never have confidence in any standard that emerges from this process, unless it is honest and based on sound and believable assumptions.

COMMITTEE ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS

FOURTH MEETING

DECEMBER 16-17, 1993

ENCLOSURE 4

FOURTH MEETING OF THE COMMITTEE ON TECHNICAL BASES FOR
YUCCA MOUNTAIN STANDARDS
December 16-17, 1993

PRESENTATION SUMMARY

SESSION I. STATE OF KNOWLEDGE REGARDING PERFORMANCE ASSESSMENT FOR AN UNDISTURBED REPOSITORY

OVERVIEW

J. Boak, (Department of Energy (DOE)) provided an overview of the use of performance assessment (PA) to predict the nominal performance of the repository. Boak provided information based upon a report in preparation that combined analyses conducted by the M&O and Sandia National Laboratory. He identified the key concerns for developing useful assessments of repository performance, among them: (1) the evaluation of the validity of underlying models; (2) the recognition of, and the proper accounting of, the coupling of dominant processes; (3) the appropriate abstraction of models and scenarios; (4) the optimization of the repository system; and (5) the judicious selection of appropriate time scales for representation of key processes.

Boak indicated that there are "degrees of validation," and that a model can be found "valid" if it is adequate for its intended purpose. He believes that the standard should require an adequate degree of confidence that should derive from an appropriate degree of realism in the models supporting a compliance determination. He pointed out that there is evidence arguing against a model of universal fracture flow at Yucca Mountain. He also noted that because of the temporary "dryout region" immediately surrounding the waste packages, the modeling of multiphase flow during this period of unsaturation will be an issue even for countries looking at saturated sites.

Boak stressed the need for the regulatory framework to afford DOE sufficient latitude to optimize the subsystems within the repository system. He noted that, in a funding-limited program, it is difficult to justify further study of subsystems (and, by implication, their optimization), if no additional regulatory credit for that particular compliance measure will result. Boak noted that high-level waste (HLW) disposal programs in other countries almost exclusively emphasize the performance of the waste package taken together with a bentonite backfill. C. Whipple chided Boak for implying that DOE would "love to put more money on waste package development," but "just can't," because of unspecified regulatory limitations. Whipple reminded him that many, including the Nuclear Waste Technical Review Board (NWTRB), have urged DOE, for years, to place greater emphasis on the integrity of the waste package. Boak defended DOE against the charge that it consistently ignored its critics and offered, as an example, the fact that DOE is using a ramp

instead of a shaft, because it listened to its critics.

In discussing the appropriate timeframe for analysis, Boak indicated that by extending the analysis from 10,000 years to 1,000,000 years, an increase of 1 order of magnitude in the estimate of the cumulative releases is realized. It was indicated that the estimated releases over 1,000,000 years would constitute a small fraction of the entire inventory. C. McCombie observed that it is not common to see calculated potential doses on the order of tenths of mSv per year (tens of mrem/year) during the first 1,000,000 years after emplacement, and asked about the factors contributing to the large early peak dose indicated in slides presented by Boak. T. Pigford commented that peak doses should be evaluated whenever they occur and should not be obscured by the use of an arbitrary timeframe cutoff. It was noted that waste package lifetime had little impact unless it approaches or exceeds the half-life of the isotopes of concern. Whipple stated that the real concern should be evaluating the uncertainty in the time between when the package fails and when a dose is delivered. The committee also expressed interest in the assumptions made when determining the individual to be used in calculating the dose and the major contributors to the dose. Questions were also raised about the number of significant digits in the calculations and the corresponding precision of the measurements used to derive those values.

ENGINEERED BARRIER SYSTEM

D. Stahl (B&W Fuel Co.) spoke to the committee on DOE-sponsored research on the waste form, the waste package, and thermal loading. He noted that these efforts (primarily conducted at Lawrence Livermore National Laboratory) have received increasing levels of funding over the past three years. He indicated that this work was predicated on an assumed containment period of 1000 years, consistent with the U.S. Nuclear Regulatory Commission (NRC) requirement for substantially complete containment for 300-1000 years (10 CFR 60.113(a)(ii)(A)). He noted that it is expected that any waste package selected will have a lifetime well in excess of 1000 years and as a practical matter, DOE would have to design for a range of mean package lifetimes of between 5000 and 6000 years just to have confidence that none would fail before 1000 years. Pigford inquired as to the speaker's definition of "failure." Stahl stated that, for purposes of the work he was discussing, a failed package was one with a breach that permitted gaseous release in excess of 10^{-4} cc (6×10^{-6} in^3) per second. When asked by the committee if this same criterion was used elsewhere in PAs for Yucca Mountain, the speaker indicated that it was not.

The focus during the post-containment period is upon controlled release from the entire engineered barrier system (EBS) (as required by NRC regulations at 10 CFR 60.113(a)(ii)(B)), maintenance of criticality control, and meeting the total system release limits of the Environmental Protection Agency (EPA) standard. According to Stahl, the functions of the EBS must include: (1) keeping water away from the waste packages by physical and/or thermal processes; (2) buffering the chemistry of any water that does reach the package, to retard corrosion and waste form degradation; (3) providing galvanic protection of the waste packages; and (4) proving a means to retard or adsorb radionuclides released from a degraded waste package.

Stahl discussed the concepts, the history, and the goals of the EBS design program. The design strategy included: (1) using a systems engineering approach; (2) taking advantage of the unsaturated nature of the proposed Yucca Mountain site; (3) minimizing uncertainties in projections of thermal effects; (4) evaluating alternative designs; and (5) interfacing with external waste management system elements (i.e., the multi-purpose canister (MPC) concept)). It is the goal of DOE's waste package program to continue the evaluation of approximately seven alternative designs and by 1996 select one or at most two design concepts. The committee was considerably interested in the impact of Environmental Protection Agency (EPA) and NRC regulatory requirements upon the design concepts pursued (e.g., the possible need for ultra-robust waste packages for the containment of C-14).

D. Shettel (Geosciences Management Institute, Inc.) spoke to the committee on the negative effects of thermal loading on the EBS. He discussed primarily on the problems associated with thermal stress on borosilicate waste glass, which he attempted to extend to spent fuel. Problems identified include: (1) the potential for significant fluid mass transport of radionuclides in high temperature gradients; (2) evolution of heat-induced porosity and increased permeability of waste forms leading to hydration, volume expansion, and fracturing; (3) the creation of an over-pressurized zone below cement caps which could considerably increase the probability of phreatic explosion; (5) heat-initiated fracture and fault networks that can become liquid conduits or "heat pipes;" (6) multiple sources of water, in the vadose zone, that can be released under high heat loads; and (7) the potential for very high heat loads to draw up water from the saturated zone. Some calculations presented suggest that the majority of the releases from borosilicate glass forms will be in the form of colloids. The following steps toward resolution of the "waste glass problem" were presented: (1) improve the durability of the glass with a better control of poor conditions; (2) use of more robust canisters; (3) emplace the waste glass in a saturated repository; (4) locate glass wastes in the coolest part of the repository; and (5) do not intersperse with spent fuel.

The committee was somewhat critical of the speaker's "worst-case" assumptions and their lack of applicability to realistic repository conditions. Pigford commented that the relevant question was not whether colloids could form, but rather whether there was any evidence to suggest that they could be transported to the accessible environment. McCombie criticized the presentation as seeming to suggest that waste form was no barrier whatsoever to radionuclide migration. J. Bahr disputed the speaker's assertion that colloid formation was not a function of solubility. F. Phillips noted that colloid transport in multi-phase systems is much slower than in single-phase systems, and that the speaker's suggestion that glass waste forms be emplaced below the water table could actually result in a significant increase in both colloid formation and transport.

R. Staehle (University of Minnesota) discussed general principles of waste container design and prediction of long-term container performance. Stating his belief that the prediction of corrosion processes is an orderly, rational process, he advanced what he called a Corrosion Based Design Approach (CBDA).

He explained how CBDA can be applied to the design of robust waste packages whose corrosion behavior can be reasonably extrapolated, using known thermodynamic principles and obtainable data. Because feedback from performance data is not possible, he readily acknowledged that design and analysis work would have to be better and more comprehensive than if feedback were available to compensate. For this reason, he believes the waste package design program should focus on a minimum number of designs and material choices. Staehle described how, given sufficient data on the near-field environment, the material, and the possible failure modes, it is possible to map the "topology of failure" for most, if not all, materials and conditions. In the speaker's view, the design of a very long-lived package is achievable, as well as the ability to engineer the local environment around the waste packages, to optimize their stability. Lastly, the speaker noted that while high-purity copper may have a certain thermodynamic attractiveness, it is by no means immune to all corrosion processes. In his view, there exists no "panacea material" that would obviate the need to comprehensively study the thermodynamic and kinetic properties of the waste package and its near-field environment.

M. Apted (Intera, Inc.) discussed the prediction of radionuclide releases from the waste container. According to Apted, European waste disposal programs place a much greater emphasis on the role of the EBS than is evident in the U.S. program. European programs view the role of the surrounding rock matrix as providing a relatively stable set of chemical and mechanical conditions over a long period of time, so that long-term performance of the EBS is not jeopardized. Apted asserted that the Europeans' greater reliance on the EBS should not be viewed as an attempt to compensate for bad sites, but as an effort instead to address irreducible residual uncertainties that will remain even after thorough site characterization. Uncertainties can be more readily controlled (or at least predicted) in an engineered system. For example, it is possible to select materials with uniform properties that can be designed and tested for integrity under a wide range of conditions. Key factors that affect the ability of the near-field to isolate waste (i.e., mean time to container failure, distribution of container failures over time, and the mode of the container failure) were discussed. It was suggested that the conductive flow barrier considered by NRC's low-level waste (LLW) program may make sense for HLW, as well. The presenter asserted that a conductive flow barrier of partially saturated gravel would, meter for meter, be 45 times more effective than compacted bentonite, decouple the near-field from the far-field environment, and eliminate the problem of the release and transport of colloids.

THERMAL EFFECTS AND RADIONUCLIDE TRANSPORT

M. Mifflin (Mifflin & Assoc.) presented evidence for periods of heavier rainfall (pluvial conditions) drawn from the historic hydrological record of the Yucca Mountain region. He discussed projections of vadose zone hydrology under such conditions and their impact on three thermal loading scenarios: the Site Characterization Plan conceptual design, sub-boiling drift emplacement, and extended dry-drift emplacement. The speaker emphasized the importance of seriously addressing the potential for climate change. It was also suggested that current plans for site characterization may not produce

sufficient information to accurately determine the groundwater flux.

T. Buscheck (Lawrence Livermore National Laboratory) presented the results of his research on the impact of waste decay heat on the thermohydrological performance of the repository. The nature and the extent of the required testing to support model validation were also addressed. Results of Buscheck's modeling were presented for a range of different thermal loads and boundary conditions. It was indicated that *in situ* heater tests are critically important for the ultimate selection of a thermal loading strategy; the size and duration of the heater test would be independent of the thermal loading strategy.

The committee was interested in the ability to monitor the predicted dry-out zone surrounding the waste packages and in the recommendations for the repository design. Buscheck indicated that the dry-out fields should establish themselves within a couple of years and could be monitored. It was noted that current modeling suggests that either a relatively "hot" or "cold" repository design would be preferable to one of intermediate temperature, and a "hot" repository would be easier to model against a dose-based compliance measure. It was also noted that large waste packages are poorly suited for colder repositories and are better suited for hotter repositories.

GEOLOGIC SYSTEM AND RADIONUCLIDE TRANSPORT

D. Hoxie (USGS) discussed saturated and unsaturated aqueous flow in the vicinity of Yucca Mountain. In his opinion, data appear to indicate that the welded tuff and Paleozoic carbonate aquifers may not be connected and, hence, radionuclides may not be exchanged between the aquifers. There is a flat hydraulic gradient to the south of Yucca Mountain that could suggest either a very conductive aquifer or the presence of very little water. It was indicated that the velocity of the groundwater flow is highly uncertain because of, in part, limited test data. Although models may be developed that can replicate the groundwater flow at Yucca Mountain, the uncertainty in the boundary conditions will make it difficult to predict the flow over long periods of time. Mifflin reminded the committee that all of these models will be highly sensitive to the overall flux of the groundwater and reiterated his concern that the potential for climate change be seriously and appropriately addressed.

E. Weeks (USGS) addressed the potential for gas-phase transport through Yucca Mountain. Beneficial as well as detrimental aspects of vapor transport were discussed. Conclusions were presented on the importance of gaseous transport for the most volatile radionuclides, the effect of barometrically-induced air flow (such as that arising from boreholes), and observations obtained during site characterization activities. It was indicated that gaseous transport is understood fairly well for natural conditions, and its importance under repository-induced conditions will depend upon the bulk permeability of the Topopah Spring welded and nonwelded units. Although data collected to date are indicative of rapid total circulation of modern air through the top of the mountain, little circulation is evident in the Topopah Spring unit. Once a

heat load is imposed by emplacement of waste, however, the resulting elevation in temperature could drive strong convective gas transport.

L. Lehman (L. Lehman & Assoc., Inc.) presented alternative conceptual models for the hydrologic flow, discussed the sensitivity of flux rates to the choice of hydrologic flow model, and provided suggestions for the EPA standard. Lehman was critical of many of the simplifying assumptions used by DOE (e.g., uniform infiltration, as opposed to focused infiltration, which can be much more rapid). She expressed frustration with DOE's unwillingness to consider higher flux rates in its total system performance assessments, asserting that efforts to date have been highly biased toward low infiltration rates. During the later public comment period, Boak (DOE) rebutted this assertion, saying that parameters have been selected from the observed range of values obtained from experiments and tests. Lehman suggested that the errors associated with DOE's conceptual model can be very large. She suggested that the standard should be fair-handed and achievable, with assurances of a fair evaluation of potential releases (i.e., consideration of alternative conceptual modes and biases), and it should reduce uncertainties (i.e., dose/risk calculations are not worth performing if they do not help you to reduce uncertainty). It was also stated that the form of the standard should remain the same, and that dose calculations should be performed, but should not be included within the standard. McCombie asked whether guidance on compliance determination should be included. Lehman indicated that some guidance should be included on the methodology and on the incorporation and discrimination of alternative models.

SYSTEM MODELS

R. Andrews (Intera, Inc.) made a general presentation on various aspects of PA, reviewing the role of PA, the PA process itself, a history of Yucca Mountain performance assessments, the results of some calculations, and some apparent consensus conclusions based on these calculations. The committee expressed interest in what constituted waste package failure; the effects of assuming gradual, as opposed to instantaneous, package failure on radionuclide release; and the assumptions made for the biosphere in estimating dose consequences. Among the consensus conclusions discussed by the speaker were: 1) predicted cumulative releases for the first 10,000 years are dominated by gaseous ^{14}C and waste package lifetime is a critical factor in determining ultimate ^{14}C releases; 2) predicted peak individual doses for most repository designs, over the first 10,000 years, are insignificant; 3) predicted individual doses after 100,000 years may be significant and are dominated by ^{237}Np (the dominance of ^{237}Np arises from recent, dramatic changes in assumptions regarding its solubility); and (4) peak doses after 100,000 years appear to be controlled by percolation flux, ^{237}Np solubility, and dilution in the saturated zone. The speaker also observed that peak individual doses are not very sensitive to thermal load variations and that for long-lived isotopes, peak individual doses are totally insensitive to canister thickness.

R. McGuire (Risk Engineering, Inc.) presented the results of EPRI's PA model, based on the DOE's site characterization Plan (SCP) design. The approach presented combined three thermal mechanisms and their probabilities and folded them into the EPRI PA calculations. The committee questioned the utility of

this treatment. Bahr indicated that the analysis would be more transparent if the choice of transport mechanism were treated explicitly. McGuire argued against the use of worst-case assumptions, stating that the standard should limit doses to an average member of a critical group or groups, rather than to the maximally-exposed individual. The speaker offered his judgment that a risk-based dose standard can be as readily applied as a release standard, but that the standard should prescribe a carefully-defined critical group. McCombie questioned the manner in which the critical group concept was applied, indicating that the method used could allow a dilution of the numbers by expanding the population to include those that are not exposed.

SESSION II. RELEASES TO DOSE AND RISK, REVISITED

G. Smith (Intera, Inc.) discussed the use of biosphere models that are used to translate calculated releases into projected doses. In discussing the reasons for developing such models, he indicated that the regulatory requirements of many countries are tied to dose rather than to release limits. The use of such models allows the decision-maker to focus on those consequences that "matter" to the public and to answer "what if" questions. Such models also allow a more ready comparison to other standards. Even in those cases where a release criterion is employed as a primary standard, it is often necessary to justify the numerical limits selected by relating them to consequences in the biosphere. A basic framework for determining critical groups was outlined, and the speaker cautioned against building the biosphere assumptions into the regulations, as they may lag behind changes to the International Commission on Radiological Protection (ICRP) limits. The speaker noted that, in his view, the strict application of the linear, no-threshold hypothesis to ^{14}C releases from a geologic repository is particularly inappropriate. He also advanced his position that dose calculations should be viewed as illustrative rather than predictive.

The committee inquired about the scientific bases available for developing the exposure scenarios, the definition and use of critical groups, the need for a reference person, and the problems associated with the use of biosphere modeling for projections over long time periods.

SESSION III. HEALTH-BASED STANDARD: ADDITIONAL CONSIDERATIONS

G. Smith discussed additional considerations for developing health-based standards. A hierarchy of criteria was discussed, which encompassed a range from the most general statements of risk objectives to the most detailed, prescriptive technical criteria. The advantages and disadvantages of various criteria limiting individual dose, individual risk, collective dose, collective risk, or specific derived performance measures were presented. Smith noted that the ICRP maintains that the environment is protected by protecting individuals.

R. Bernero (NRC) presented NRC staff views on the use of PA in the evaluation and the licensing of HLW disposal (a copy of his prepared remarks as submitted to the NAS Committee is in Enclosure 5). In his oral presentation, Bernero indicated that PA will facilitate the systematic analysis of the standards and can be used to look at the degree of compliance. Its use also affords the

regulator a means to identify where to concentrate and where not to concentrate regulatory attention. In Bernero's view, its most important use for such a first-of-a-kind endeavor is its value in retrospectively evaluating and reappraising the existing regulatory framework, and even the standard itself.

Bernero acknowledged that the existing framework in 10 CFR Part 60 arose not from any PA of assumed repository performance, but was a conscious effort to allocate repository performance, using tests of acceptability that would preclude over-reliance by DOE on a single barrier. In short, these subsystem requirements specify that the container should not leak for a long time; when it does leak, it should leak slowly, and, once released, any radionuclides should take a very long time to reach the biosphere. He emphasized that the standard's evolution should be an iterative process, responding to the acquisition of knowledge and improved understanding. Bernero presented his view that the Energy Policy Act provisions for reliance on active institutional controls could result in substituting one uncertainty for another, and that it is not prudent to rely on the effectiveness of active controls for long periods of time.

The committee expressed interest in whether NRC was entertaining the possibility of fundamental revisions to its Part 60 regulations. Budnitz, in particular, criticized pre-emplacement groundwater travel time as a "lousy surrogate" for radionuclide retention in geologic media. Bernero responded that, while NRC was not anticipating any fundamental revision, NRC is obligated to conform its regulations in Part 60 to any EPA standard that is eventually promulgated. Bernero was questioned as to the necessity to comply with subsystem requirements if the total system requirement is met. Bernero responded that NRC had anticipated the need for flexibility when applying the criteria to a specific repository, when it promulgated 10 CFR 60.113(b). Interest was also expressed in the development of additional NRC guidance or clarification of its definition of "substantially complete containment." Bernero noted that considerable progress has been made by NRC staff in addressing this need, but did not specify a date for publication.

PUBLIC COMMENTS

Boak (DOE) took exception to assertions made by Lehman. These assertions were that the INTRAVAL test case was not well posed and that DOE is ignoring fracture flow. He also stated that there is a reasonable ability to estimate future climate.

R. Neill (Environmental Evaluation Group) discussed various issues related to the committee's charge from the perspective of his experience with the Waste Isolation Pilot Plant (WIPP) facility. He offered his opinion that the collective dose attributable to ^{14}C, which is projected to result in (globally) approximately 3000 health effects over 10,000 years, should not be dismissed. The effectiveness, or lack thereof, of institutional controls, during the recent history of the WIPP site, was described. At WIPP, there has been an 88 percent failure rate in the proper processing of drilling requests, and the accuracy of land-use records even for the most recent past was characterized as being far from adequate. Neill stated his belief that deep

geologic disposal is feasible, while also cautioning that an inability to adequately address human intrusion is tantamount to admitting that geologic disposal is not feasible.

S. Frishman (Nevada Nuclear Waste Project Office) commented that the committee's findings should not be inconsistent with the Nuclear Waste Policy Act mandate to protect the environment. Frishman advanced his view that a dose standard, alone, is not sufficient to protect the environment, and that dose calculations may overemphasize certain radionuclides.

COMMITTEE DISCUSSION

R. Budnitz shared a preliminary proposal that the standard be formulated in a manner similar to NRC's reactor safety goal. It was suggested that the standard could have, as its underlying premise, the promise that no individual's risk of cancer attributable to the repository would exceed 10^{-3} times his/her current risk of cancer. He asked that the committee consider whether such a standard is implementable, whether there is a technical basis for establishing such a premise, how it might be formulated so that the public could understand the standard, and whether calculations could be developed that would support compliance with this type of standard.

J. Ahearne cautioned that although a "safety goal" may be simple in its statement, it can be extremely difficult in its development. Pigford noted that, although the concept may be clear to the technical community, it is premature to suggest that the public would support such a formulation. Pigford noted that he believes the committee should focus first on what is scientifically supportable and second, on how it can best be explained to the public. A brief discussion followed, concerning risk-based standards and the history of the reactor safety goal.

W. Gunter (EPA) acknowledged that under the Energy Policy Act of 1992, the NAS is at liberty to recommend whatever it wants. However, Gunter admonished the committee to pay close attention to the deliberations accompanying the repromulgation of 40 CFR Part 191 and to recognize that EPA will still be legally obligated to explain any differences between standards promulgated for Yucca Mountain and EPA's current standards for the storage and disposal of HLW. He requested that the committee explain why it is recommending something different from Part 191, if it does recommend something different in form or content. McCombie noted that the committee has an obligation to explain its reasoning for any recommendation that it makes, even (or especially) if it endorses an approach similar or identical to that taken for 40 CFR Part 191.

NATIONAL ACADEMY OF SCIENCES COMMITTEE ON THE TECHNICAL BASES
FOR YUCCA MOUNTAIN STANDARDS
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U.S. NUCLEAR REGULATORY COMMISSION STAFF VIEWS ON THE USE OF PERFORMANCE ASSESSMENT IN THE EVALUATION AND LICENSING OF HIGH-LEVEL WASTE DISPOSAL

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INTRODUCTION

This Committee has invited me here today to explain how the Nuclear Regulatory Commission, as the implementing regulatory agency, will use performance assessment in evaluating a license application for a geologic repository and, in particular, how uncertainties in both data and modelling will be taken into account.

In brief, the NRC views performance assessment as the primary link, or bridge if you will, between the vast quantity of data that will be obtained -- during repository design as well as throughout site characterization and the required performance confirmation program -- and those regulatory decisions NRC must make regarding the overall safety and licensability of a proposed repository. Performance assessment provides the means to quantify both the magnitude and likelihood of the potential health, safety, and environmental consequences of a nuclear waste repository. The discipline of performance assessment affords the regulator and other interested parties the opportunity to compare these potential effects to agreed upon standards of acceptability and to represent the findings of such analyses and comparisons in a form understandable and useful to decision makers and the public. Although every effort will be made to predict the post-closure performance of a repository in rigorous quantitative terms, such calculations cannot be the sole objective of the

assessment. Neither, for that matter, should a simple comparison of such a performance estimate to regulatory performance limits suffice as the sole basis for determining acceptability without first explicitly accounting for the uncertainty intrinsic to these calculations. Another important objective of performance assessment is to understand the performance of significant subsystems or elements of the overall system in a way that permits optimization of those elements to ensure that the overall performance objective is achieved.

Perhaps the most significant benefit of iterative performance assessment for such a first-of-a-kind endeavor, however, is that it affords us an opportunity to systematically reflect on what we are doing and to evaluate the criteria we are attempting to apply. Are they sufficiently protective? Are they unduly stringent? Has something important been overlooked? Have we established an appropriate regulatory framework robust enough to provide a sound basis for licensing an untried technology? I will have more to say later on the importance of using performance assessment to reexamine questions such as these.

ROLE OF PERFORMANCE ASSESSMENT IN THE REGULATORY CONTEXT

Whatever the ultimate form of final EPA standards, the NRC will be required to thoroughly evaluate the overall performance of a geologic repository at Yucca Mountain or elsewhere before it can arrive at any determinations of its safety and licensability. In order to support such determinations, NRC requires the Department of Energy (DOE) to provide a comprehensive performance assessment as part of its license application. NRC intends to review all parts of DOE's

performance assessment at some level, and will review in depth those selected portions which NRC judges to be of greatest import to overall repository safety. In addition, NRC expects to perform its own independent calculations of overall repository performance in order to check DOE's assessment of the performance of a proposed repository. The NRC will pay particular attention to the underlying assumptions DOE has employed to ensure that appropriate alternatives have been considered in the selection of conceptual and process models as well as the assignment of key parameter values.

Long before the formal license application is submitted, however, NRC believes that iterative performance assessment should play a pivotal role in guiding site characterization and directing our attention, as regulators, to those aspects of repository performance that are of the greatest safety significance. We believe that the evolving capability of NRC to conduct performance assessment in conjunction with our continuing, open interactions with DOE throughout the pre-licensing period will significantly reduce the degree of uncertainty associated with the evaluation of repository safety and effectiveness.

SOURCES OF UNCERTAINTY

It has been generally recognized that demonstration of the long-term safety and efficacy of a particular repository will be subject to considerable uncertainty. This does not mean that safe geologic disposal cannot be accomplished or that implementable environmental standards cannot be developed. It does, however, underscore the importance of exerting every effort to identify, reduce as much as possible, and manage residual sources of

uncertainty to such a level that sound regulatory decisions can be made. What, then, are the sources of this uncertainty?

The NRC concerns itself with two broad categories of uncertainty, namely, regulatory uncertainty and technical uncertainty. Regulatory uncertainty with regard to the EPA standards or NRC's implementing regulations can arise when there is doubt about what must be proven to demonstrate compliance with a given requirement. Regulations may be ambiguous or contain unclear text which may make evaluations of compliance more difficult than they need be. I will not say much more about this category of uncertainty, other than to assure you that NRC, with the help of its contractor, the Center for Nuclear Waste Regulatory Analyses, is engaged in a process whereby such uncertainty, particularly in our regulations, may be identified and corrected prior to receipt of a license application. We would also hope that as EPA seeks to promulgate new standards for HLW disposal, that care will be taken to avoid the introduction of unnecessary regulatory uncertainty.

Technical uncertainty, on the other hand, would appear to be unavoidable in any projections of the performance of a repository as a result of the long time period of concern during which relatively rare geologic, climatic, and human-initiated disruptions might occur. Technical uncertainty will be encountered and will need to be dealt with regardless of the form EPA's standards or NRC's implementing regulations ultimately take. Technical uncertainty can arise from incomplete knowledge of the repository system at the time of repository closure; it may arise from our imperfect ability to predict the future states of the environment within which the repository must

perform; or it can emerge from inadequacies in the mathematical abstractions, or models, we construct to forecast the performance of a repository within that environment.

Site characterization, of course, will be the primary method employed to reduce technical uncertainty by providing information about the physical and chemical processes occurring at or near the site. However, site characterization is expensive and time consuming and may be, itself, disruptive of the repository site. These considerations, along with the limited resources available for testing, place practical limits on the amount of data that can be acquired during site characterization. Through its open interactions with DOE and other parties, NRC endeavors to ensure that performance assessment will be effectively used to facilitate the acquisition of essential information with minimal disruption of the site.

USE OF PERFORMANCE ASSESSMENT TO TREAT UNCERTAINTY

In addition to reviewing and commenting on the Department's Site Characterization Plan (and its periodic updates) the NRC staff is developing its own performance assessment capability to help evaluate the sufficiency of site characterization. The NRC staff continues to encourage DOE to regularly assess the projected performance of a repository during the site characterization process. Such an iterative process, we believe, will provide an opportunity to evaluate the adequacy of current information about the site and to modify characterization plans so that studies are appropriately focused on the most important areas of uncertainty in projected performance. Performance assessment is a powerful tool that can be used systematically to

define and illuminate many of the technical uncertainties I have described. Performance assessment affords an opportunity to identify and evaluate the assumptions and bases for those mathematical models that are used to estimate repository performance. In the case of data for which uncertainty can be quantified by error bounds or probability distributions, performance assessment methods have been developed for understanding the way in which the uncertainty of that data propagates through the various mathematical models employed and for calculating the impact of that uncertainty on the estimates of performance. Uncertainty in the future states of nature in which the repository must function are treated probabilistically in performance assessment. Possible future states or scenarios are assigned a probability, and the response of the repository system to that scenario is estimated. Uncertainties in the models themselves can be evaluated using performance assessment both qualitatively and quantitatively. Should alternative conceptual models exist for the performance of the repository and sufficient data is not available to select a single concept, performance can be calculated on the bases of each model in order to ascertain whether any resulting differences in calculated performance are significant enough to preclude a given regulatory decision. Such comparisons can be useful whether the alternative concepts relate to boundary conditions for the model, the model geometry, or a particular physical process and its manifestation as implemented in the model.

It is important to keep in mind that iterative performance assessment will not cease if DOE is granted a license to emplace waste. NRC regulations explicitly require that -- and I quote -- "The geologic repository operations

area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained..." As currently specified, the retrieval period can be up to 50 years, unless a different period is approved by the Commission. During this performance confirmation period, data will be collected with regard to the actual performance of the repository system subject to the heat loads and radiation fields produced by emplaced wastes. These data may provide additional assurance that the conceptual models relied upon during licensing accurately bound the behavior of the repository system and confirm projections based on shorter-term laboratory data. If, however, repository performance is found to be significantly different from that initially projected from laboratory data, modifications can be made to the engineered barriers, or, if necessary, waste packages may be retrieved and remedial actions taken.

Despite the best efforts of the DOE, and those of the NRC, to reduce uncertainty, there will remain "residual uncertainty" regarding data, models, and future states of the repository. The significance of such uncertainty will need to be addressed in deciding whether there is reasonable assurance that the EPA standards will be met. Judgment will then become the principal means for addressing residual uncertainty. The judgments of technical experts will be needed to characterize residual technical uncertainty to the extent practical, to estimate the effect of that uncertainty on overall repository performance, and to assess the effects of unquantifiable uncertainty. Although the NRC recognizes that expert judgment will be widely used in a

repository performance assessment, we do not consider it acceptable to substitute expert judgment for field and experimental data, or for technically rigorous analyses if they are reasonably obtainable.

Decision makers, too, will be called upon to address the regulatory significance of residual uncertainty. The licensing board and the Commission will ultimately have to examine residual uncertainty using NRC's established licensing process to consider all available information presented by the parties in the proceeding and to scrutinize the scientific bases underlying the data presented.

THE REGULATORY FRAMEWORK

At this point in my presentation, I would like to turn my attention to that regulatory framework within which performance assessment must be conducted and which, ultimately, will define "reasonable assurance" for long-term geologic disposal of spent fuel and high-level radioactive wastes.

The legislation governing the development of a geologic repository for disposal of high-level radioactive wastes codifies a national commitment to geologic disposal as the method of disposal preferred over other available alternatives. A fundamental premise undergirding this decision is that we will dispose of waste in a manner such that future generations will not be exposed to radiation hazards that we would find unacceptable for ourselves today. In addition, this premise is motivated by certain equity considerations that we, who benefit from electricity generated by nuclear fission, should assume the burden of disposing of the resulting wastes.

The national decision to pursue geologic disposal grew out of an evolving appreciation of the need to protect public health and safety, both now and in the future and an increasing recognition that it is not a responsible national policy to store spent fuel at more than seventy reactor sites indefinitely.

Under the existing U.S. regulatory framework, NRC will be required to conform its regulations to EPA's environmental standards and to evaluate compliance of any proposed repository with NRC's conforming regulations. In addition, as directed by the Nuclear Waste Policy Act, NRC technical criteria must also provide a system of multiple barriers and include restrictions on retrievability. Consistent with the mandate to require a system of multiple barriers, NRC established within its implementing regulations three subsystem performance objectives for particular barriers, specifically prescribing: (1) the length of time during which containment within the waste packages must be substantially complete, (2) an acceptable fractional release rate from the engineered barrier system, and (3) a limit on pre-emplacement groundwater travel time.

We are well aware of the many questions that have arisen with regard to the efficacy of quantitative subsystem performance objectives, generally, and those incorporated in our regulations, in particular. It is important to note that the Commission recognized the need for flexibility in applying the subsystem criteria. Alternative release standards, travel times, or waste package containment periods may be approved by the Commission on a case-by-case basis taking certain factors into account. It should be recognized that, in implementing the concept of multiple barriers through these subsystem

objectives, the Commission sought to define simpler measures of subsystem performance which, if met, would enhance confidence that the overall performance objective will be achieved. The NRC staff is actively reexamining these criteria to ensure that they are indeed appropriate measures of subsystem performance.

The NRC staff believes that EPA can develop, with the guidance of this Committee, an appropriate health-based standard which limits either individual or population doses or risks. We also believe, however, that there are clear advantages for the standard to be expressed as a derived quantity if, in its derivation, appropriate and relevant assumptions are employed such that the resulting quantity or concentration limits can be demonstrably linked to an overall safety objective.

Yucca Mountain is located in an arid environment far away from any current human residence. Radioactive materials released from a repository at this site would be unlikely to reach currently populated areas until far in the future when radioactive decay and dilution of the radionuclides would have significantly reduced the resulting doses. At the opening meeting of this Committee, earlier this year, Margaret Federline offered the NRC staff's opinion that, as with other radiation protection standards, an individual protection standard for a repository should not attempt to protect all individuals, under all conceivable circumstances, at all times in the future. It does not, for example, seem reasonable to protect a hypothetical farm family located at the repository boundary if it appears unlikely that such a family will ever exist.

As an alternative, one could assume that current population locations and habits remain unchanged indefinitely. Such an assumption has the advantage of recognizing the relative isolation of Yucca Mountain. The disadvantage, of course, is the potential that a resulting standard may not be sufficiently conservative if changes at the site, such as population growth and increased utilization of groundwater, lead to higher doses than would be projected based on current conditions. A more realistic scenario might assume exploitation of groundwater near Yucca Mountain as a supplement to a municipal water supply for a regional population.

Estimation of a collective dose associated with a repository would presumably involve estimation and summation of the individual doses anticipated for each person exposed to releases from the facility. This would necessitate fairly detailed demographic projections, including the number of potentially exposed individuals, their locations, and the usage rates for each person for each exposure pathway. Truncation of the summation of individual doses may be appropriate, either as a function of distance from the facility or at some de-minimis or "negligible risk" individual dose rate.

The NRC staff has repeatedly expressed its view that the release-limit format of EPA's 1985 standards is much easier to implement in a licensing review than are dose limits because assumptions about long-term population locations and lifestyles would not need to be evaluated as part of a site-specific licensing review. If EPA could revise its release limits (or derive new ones) in a way that can be demonstrably linked to health and safety objectives, we believe

the release limit format should be retained. To do so, EPA would need to first explicitly articulate a safety objective and then convert the safety objective into a limit on permissible releases or concentrations of radioactive material in the environment.

We do not believe, however, that it is appropriate to apply release limits to a set of site-specific conditions if those conditions were not encompassed within the range of generic assumptions used to derive the release limits. In deriving the 1985 release limits, EPA accounted only for releases to rivers and oceans when, in fact, gaseous release and withdrawal of groundwater are the most relevant release pathways at an unsaturated site such as Yucca Mountain. Members of this Committee are well aware of the issues related to carbon-14 and I will not dwell on it here. I would note, however, that, while carbon-14 serves as an example of "revealed stringency," we believe that there may be other, somewhat more subtle, problems with the derivation of the existing release limits. From a preliminary review of EPA's estimate of the number of thyroid cancers that could potentially develop in human populations over the next 10,000 years due to the release of iodine-129 from a geologic repository, members of my staff have identified certain assumptions which appear to result in unwarranted conservatism contributing, if you will, to a "veiled stringency." For example, more recent analyses than those used in EPA's technical support documents suggest that negligible amounts of iodine are taken up by crops from contaminated soil and that uptake of iodine by the thyroid is significantly less than EPA assumed. The NRC staff is concerned about the effect that a combination of conservative assumptions may have on the level of the standard's overall stringency and implementability at any

geologic repository if similar problems emerge from a careful review of the release limits for other radionuclides. For iodine-129 this conservatism is masked because the limits, despite the overly conservative assumptions made in their derivation, still allow the release of the entire iodine-129 inventory of the repository. We are currently evaluating whether we should extend this informal examination to a more formal review of the assumptions supporting the release limits for other isotopes. We will be happy to share with the Committee the results of our work thus far if it would be of value to your deliberations.

In addition, the NRC staff has expressed concern that EPA has not provided adequate technical bases to support the view that its individual and groundwater protection requirements were derived to provide an appropriate level of safety for geologic disposal and are, in fact, technically achievable for any repository over a 10,000 year period of concern.

The NRC staff has repeatedly questioned EPA's use of its analyses of the performance of hypothetical repository sites as the "technical achievability" basis for its 1985 standards. We have expressed the view that EPA should place greater emphasis on comparisons with other risks and radiation protection standards. This is not to say, however, that our evolving technical judgment of what "best available technology" can realistically accomplish should not play some, even an important, role in the establishment of standards for geologic disposal of high-level wastes. It is important, however, that any judgment of "technical achievability," no matter how soundly supported, include an equally sound assessment of the resulting level of

protection provided by what is deemed "achievable." The "technology-based" approach to standard setting, if done right, may still be worthy of consideration, if a realistic assessment can be made of the best level of protection that repository technology can provide and if that level of protection is found to correspond favorably to the level of protection afforded by other recognized and accepted health and safety standards. Our best, realistic estimates of the level of protection afforded by geologic disposal must be compared not to a standard of "zero risk," but instead to the level of radiation protection we would find acceptable today, no more and no less.

IMPACT OF POTENTIAL REVISIONS TO THE EPA STANDARD FOR YUCCA MOUNTAIN

If, in response to recommendations of the NAS, EPA elects to abandon the cumulative release limits in the 1985 standards in favor of a dose or risk standard, NRC's approach to performance assessment and review of a license application would, of course, need to be reexamined. As I mentioned earlier, one of the truly attractive features of EPA's 1985 standards, from the vantage point of implementation, was the specification of allowable levels of releases of radioactive material, rather than limits on projected dose. Projection of doses over thousands of years inevitably involves speculation about the locations of future people, individuals or populations, their lifestyles, and similar factors. The NRC staff cannot emphasize strongly enough its position that any dose standard should explicitly include some specification of a "static" or "reference" biosphere in order to avoid the potential for undue speculation during a licensing review. Should the NAS recommendations and/or EPA's standards fail to specify the conditions for application of an

individual dose standard, the Commission would have to do so, preferably well in advance of receipt of a license application.

With respect to iterative performance assessment development, adoption by EPA of a dose or risk standard would necessitate expansion of the scope of ongoing dosimetry model development and implementation to reflect changes for individual or collective dose limits. Furthermore, adoption of a dose standard will probably require some additional site characterization efforts by DOE and corresponding review efforts by the NRC. As alluded to before, it might be necessary to project the effects of human activity at the site for thousands of years, at least to the extent that changes within the biosphere are permitted or defined under the standards.

In addition, DOE may need to more precisely estimate the concentrations, rates, and timing of release of all radionuclides than would be necessary to demonstrate compliance with EPA's 1985 standards. For example, EPA's cumulative release standards are less sensitive to the rate of radionuclide release as their focus is the total cumulative releases over 10,000 years. However, for an individual dose standard, it could be much more important to know whether nuclides are released sequentially or simultaneously as the resulting doses would need to be summed for simultaneous release. The additional information that will need to be collected during site characterization will be among some of the most difficult to measure -- especially retardation factors and dispersion during groundwater transport. The Energy Policy Act of 1992 directs DOE to provide post-closure oversight of the Yucca Mountain site to "prevent any activity that poses an unreasonable

risk of ... increasing the exposure of individual members of the public to radiation beyond allowable limits." "Activity" in this context could be interpreted to include more than just human intrusion. For example, occupancy of areas near Yucca Mountain and use of groundwater in those areas could be viewed as "activities." Prevention of such occupancy by post-closure oversight could be assumed to be effective in preventing any doses beyond allowable limits--even if natural disruptive events were to occur. Such an interpretation would profoundly alter the nature of NRC's licensing review. DOE would no longer have to demonstrate that a repository would be passively safe. Instead, DOE would have to develop contingency plans for remediation of site impacts if disruptive events should occur. Performance assessment would focus on worst case estimates of releases to support development of remediation plans and the NRC's licensing review would then focus on the adequacy of these remediation plans.

CONCLUDING REMARKS

Returning once again to the initial subject of this presentation, the NRC staff continues to believe that performance assessment is a powerful analytical tool which can provide significant support for regulatory decisions about a nuclear waste repository provided certain conditions are met.

First, it is essential that aspects of performance that can reasonably be quantified, including the unavoidable uncertainties, be quantified to the extent practicable. The many scientific disciplines involved in estimating repository performance, such as geology, geochemistry, materials science,

groundwater hydrology, and others, must be exercised to their maximum extent in order to quantify as much of repository behavior as can be substantiated. Not only will such a challenge illuminate many important sources of uncertainty, the rigorous application of these disciplines will clearly identify what cannot be quantified.

Second, mathematical modelers or performance assessors must be very sure that their activities incorporate quantitative and qualitative information from all appropriate scientific disciplines. It will be important that the models used accurately reflect the current state of knowledge in each discipline and not attempt to quantify through models that which is beyond current human knowledge.

Finally, regulatory decision-makers will have to honestly acknowledge, accept, and communicate the limitations of certainty involved in predicting performance and behavior far into the future. Such uncertainty, as stated before, is inevitable when confronting disposal of long-lived wastes. Given sufficient diligence and care on the part of all participants in this endeavor, I am confident that these conditions can be achieved and that performance assessment will contribute significantly to decisions on the long-term safety of a geologic repository.