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TRANSMITTAL OF TECHNICAL SUMMARY AND REPORT: "RECOMMENDATIONS TO U.S. DEPARTMENT OF ENERGY (DOE) MANAGEMENT RESULTING FROM DOE'S WORKSHOP ON THE USE OF EXPERT JUDGMENT IN DECISION-MAKING;" ALBUQUERQUE, NEW MEXICO; NOVEMBER 18-20, 1992

In response to a request from the Nuclear Waste Technical Review Board, DOE held a workshop to examine various methods and applications of expert judgment and decision analysis and to prepare specific recommendations for improving DOE's use of expert judgment in the performance assessment program. The workshop was held in Albuquerque, New Mexico, November 18-20, 1992. As a result of the workshop, the steering committee prepared a report that analyzes the workshop proceedings and lists recommendations for consideration by DOE management as to the future use of expert judgment within the Office of Civilian Radioactive Waste Management program. The steering committee was chaired by Ardyth Simmons (DOE) and the membership was comprised of the following DOE staff and Yucca Mountain Site Characterization Project Office participants and contractor staff: Jeremy Boak (DOE); Robert Shaw (Electric Power Research Institute); Bruce Judd (Decision Analysis, Inc.); Holly Dockery (Sandia National Laboratories); Jean Younker, Marshall Weaver, James Duguid, Lynn Hoffman, and Abraham Van Luik (Civilian Radioactive Waste Management System Management and Operating Contractor).

The report reflects the thinking and opinions of the majority of the steering committee and was reviewed extensively both internally by project staff and management, and externally by the workshop participants. Every attempt was made to resolve review comments and to consider the majority opinion in preparing the report and the recommendations. However, neither the report nor the recommendations is intended to reflect the opinions of all the workshop participants.

Transmitted herewith is the referenced report (enclosure 1); a technical summary of the proceedings prepared by Roy F. Weston, Inc., (enclosure 2); and the workshop agenda (enclosure 3).

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Please direct any questions or comments regarding this workshop or the documents transmitted herein to Ardyth M. Simmons at (702) 794-7998.

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RSED:AMS-3861

Enclosures:
1. Recommendations to DOE Management Resulting from DOE's Workshop on the Use of Expert Judgment in Decision-Making; Albuquerque, New Mexico; November 18-20, 1992"
2. Technical Summary of DOE's Workshop on the Use of Expert Judgment; November 18-20, 1992; Albuquerque, New Mexico
3. Agenda for Expert Judgment Workshop, November 18-20, 1992

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Recommendations to U.S. Department of Energy (DOE) Management Resulting from DOE's Workshop on the Use of Expert Judgment in Decision-Making

Albuquerque, New Mexico
November 18-20, 1992

Abstract

This report provides a review and summary of workshop discussions on the use of expert judgment in decision-making. The workshop was convened by the U.S. Department of Energy (DOE) in response to a request from the Nuclear Waste Technical Review Board (NWTRB) for specific recommendations for improving the DOE's use of expert judgment in the performance assessment program. In workshop discussions, expert judgment was viewed as a mechanism for codifying, quantifying, and documenting scientific information and knowledge and bringing it into the decision-making process. A number of individuals with expertise in the use of expert judgment were invited to serve as panel members or to participate in focused discussions.

Applications of expert judgment within the Office of Civilian Radioactive Waste Management (OCRWM) program were reviewed, including ranking candidate sites, selecting a preferred underground exploratory facility design, and prioritizing site characterization testing. Expert judgment is also used to provide information to licensing boards. According to panel members, elicited expert judgment has been presented and successfully defended before reactor licensing boards in a number of cases. The length of time required to conduct a thorough elicitation was a drawback repeatedly raised during workshop discussions, as were issues related to techniques for combining experts' opinions on controversial topics. Another issue discussed at the workshop was the importance of allowing for management prerogative when using decision-aiding methods.

This report lists recommendations for consideration by DOE management related to future use of expert judgment within OCRWM. These recommendations are the product of the workshop steering committee and do not necessarily reflect the opinions of all the panel members. These recommendations include:

(1) evaluating decision-analysis approaches alternate to those used by DOE to date;
(2) developing a flexible plan for future use of expert judgment in the program;
(3) initiating training in quality decision-making and the formal use of expert judgment;
(4) participating in a test case involving the use of expert judgment in a regulatory environment;
(5) holding a meeting with stakeholders to gain insight into alternative views on the use of expert judgment in decision-making; and,
(6) investigating the use of expert judgment by other government bodies.

ENCLOSURE 1

Introduction

The U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) sponsored a workshop in Albuquerque, New Mexico, November 18-20, 1992, on the use of expert judgment in decision-making. It was attended by over 120 participants, including senior OCRWM management; managers and technical staff representing Yucca Mountain Project participant organizations; university faculty and consultants with experience in the application of expert judgment in decision-making; and oversight groups such as the State of Nevada, affected counties, the Environmental Protection Agency (EPA), and the U.S. Nuclear Regulatory Commission (NRC) and its contractors.

The workshop was held to fulfill a commitment to the Nuclear Waste Technical Review Board (NWTRB). In its Fourth Report to Congress, the NWTRB recommended that the use of expert judgment in DOE's current performance assessment program and in the performance assessment exercises carried out by other organizations be examined in a workshop forum. The objective suggested for the workshop was to propose specific recommendations for improving the use of expert judgment in future performance assessment iterations. Workshop planners broadened the workshop objective to enhance the quality of DOE/OCRWM decisions through the appropriate use of expert judgment.

This report provides an assessment for senior OCRWM management prepared by the workshop steering committee of the resulting workshop. In particular, it reviews the principles of and experience in applying the judgment of qualified experts to technical and programmatic decisions for the high-level waste program. This report begins by defining and describing expert judgment and its role in making high-quality decisions. It then presents key issues for management's consideration with respect to the application of expert judgment, including successes and failures, strengths and weaknesses, and some important lessons learned from past experience, especially in the regulatory arena. Workshop planners broadened the workshop objective, proposing that it be conducted to enhance the quality of OCRWM's use of expert judgment in making future decisions. The recommendations do not necessarily reflect the opinions of the panel members.

Definition and Description of Expert Judgment

Expert judgment is the term applied to the general process that supports decision-making based on the relevant experience of the decision-maker or others who have been consulted. The exercise of expert judgment may be informal or informal, unstructured or structured.

Whenever decisions are made, expert judgment is used in one form or another, even when scientifically collected data are available. As suggested by the workshop's keynote speaker, Professor Ronald A. Howard: "Data are meaningful only when interpreted according to models created from the knowledge of experts. However, human judgment is always used in decision-making, for example, in law (whether to litigate or settle), in medicine (whether to

operate), or in politics (when to launch Operation Desert Storm). Action determined by data rather than by expert judgment is the exception, not the norm."

Expert judgment may be implicit or explicit, qualitative or quantitative, formal or informal. To illustrate these distinctions, a decision-maker choosing whether or not to initiate a series of surface-based tests at Yucca Mountain might explicitly consider the possible results of the experiments before beginning drilling; or, the consideration of possible results might be implicit in a decision whether or not to start drilling. If the decision- maker consults a hydrologist for information on the possible results, the expert might give qualitative information (e.g., information on matrix flux in the unsaturated zone (UZ)) or quantitative information (e.g., data from this experiment will narrow the current uncertainty about UZ flux in the matrix by a factor of 3 to 5). Finally, the method used to obtain information from the hydrologist either might be informal (e.g., a direct question by the decision- maker) or formal (involving the formal elicitation of the hydrologist's information by a third party who specializes in assessing such judgments). The formal elicitation would include an assessment of the hydrologist's level of uncertainty about the possible results.

Professor Howard set forth prerequisites for making high-quality decisions. Decision-makers can spend from minutes to months ensuring that these characteristics are present; the right amount of time depends on the decision to be made. For each decision, the appropriate number and timing of interactions must be considered among decision-makers, experts, and analysts. The decision must be framed correctly so that the scope and focus of the decision is appropriate for the situation. Alternatives must be evaluated that are creative, significantly different, and that can be acted upon. Of importance is having the right information, which must be accurate and reliable, and include what is known and what is not yet known about each variable affecting the decision. All the criteria to be used in evaluating the alternatives must be clearly stated. The logic and analysis require correct reasoning, including a level of modeling appropriate to the decision. Communication must be clear and understandable to all affected constituencies. And, there must be a commitment to action by the decision-makers after information has been gathered and the analysis is complete.

Professor Howard explained that procedures have been developed to measure the degree to which these characteristics are present in any decision, and these measures are commonly taught to executives in training programs on decision quality. Such programs also include training in the appropriate amount of effort to expend on each characteristic for any particular decision.

Workshop discussions emphasized the need for the right information supported by the right framework, the right communication, and the right commitment to action. Failure in any of these areas can render useless even the best information-gathering activities.

The Role of Expert Judgment

Quality decision-making requires balanced, accurate incorporation of expert judgment/human knowledge, including properly interpreted data. Levels of formal modeling and analysis that might be used to support a major decision include the following:

- "pilot-level" analysis, used to identify important factors about which expert judgment and quantitative models should be pursued;
- "full-scale, integrated" analysis, as might be appropriate in a business decision with a clearly identified decision-maker; and
- "defensible" analysis, such as might be required to support recommendations regarding the suitability of the Yucca Mountain Site for repository development or licensing.

Incorporating expert judgment in defensible decision analyses requires a high level of professional competence, careful planning, and skillful execution. A good decision analysis is much more difficult and much more powerful than it appears. Essential to incorporating expert judgment into decision-making is the degree of uncertainty associated with the judgment. For example, it may be very important for the decision-maker to find flexible alternatives that can be adjusted in the future as uncertainties are changed.

Various formal methods are used for eliciting expert judgments (including their uncertainties), for recognizing and correcting biases that may be present in such judgments, and for incorporating the judgments of multiple experts. These methods are well-documented and staff can be taught to apply them properly, but the training requires a substantial time investment.

OCRWM decision-makers face many challenges. These include the need to establish for each major policy decision the appropriate extent and formality of incorporating expert judgment; in particular, whether such judgments should be implicit or explicit, qualitative or quantitative, informal or formal. Such determinations can be made using the principles of decision quality, which have been successfully taught and applied in several energy-related industries. Time and effort spent in formal elicitation of expert judgment and in analysis of policy decisions is viewed as an investment, and choices must be made regarding the appropriate level of time and personnel resources to be committed. Experience from corporate decision analyses and elicitations of expert judgment indicates that benefits from improved decisions typically outweigh costs. Another challenge for policy-makers is establishing the appropriate role for peer review as a part of a defensible decision-making process. If structured properly, peer reviews are straightforward extensions of the process of assessing expert judgment and therefore help to enhance the quality, defensibility, and scientific acceptability of technical decisions.

Record of Applications of Expert Judgment

OCRWM Experience

Expert judgment plays a role in any technical or regulatory decision. OCRWM's use of expert judgment ranges from explicit but less-formal use, such as developing the Site Characterization Plan, peer reviews, and design reviews, to explicit and more formal use in the site-evaluation process and in prioritizing data needs.

Expert judgment was modeled by decision analysis in the studies summarized in Table 1. The multiattribute utility analysis (MUA) methodology that was used to rank candidate sites for site characterization was widely reviewed, both by the National Academy of Sciences and the broader scientific community, and reviews were almost uniformly favorable. Issues were raised during the November workshop about whether DOE managers acted appropriately when they applied additional factors to adjust the order of preference derived from the MUA to arrive at the final three sites nominated for site characterization. The general position of those managers who voiced their views at the workshop was that managers should always have the prerogative to consider additional factors when utilizing results from decision-aiding methods such as MUAs. However, some workshop attendees voiced the opinion that the decision is most defensible when important factors are suggested at the beginning and are then included explicitly in the analysis. This viewpoint is consistent with a point from the keynote address, i.e. that proper framing of the question is crucial in obtaining a useful outcome from decision analysis.

Another instance in which the structured use of expert judgment played a key role in OCRWM decision-making is the analysis of alternative design options for the Exploratory Studies Facility (ESF). The analysis found that the best options were those that result in the highest probability of producing a properly functioning, closed repository. Dominant factors influencing this probability included (1) the overall ESF schedule of completion; and (2) the responsiveness to concerns raised by the NRC and NWTRB. According to the expert panel on OCRWM management, the selection of an option that delays completion or fails to respond to NRC and NWTRB concerns is more likely to lead to termination of the repository program, a major uncertainty for obtaining a successful repository. OCRWM management assigned probabilities for continued program viability and then based the selection of the current ESF design on the overall results of the analysis.

A third example in which OCRWM decision-makers used formal expert judgment methods is the analysis of the benefits and risks of exploring and testing in the Calico Hills unit, a geologic formation which underlies the potential repository horizon at Yucca Mountain. In this study, the possibility of adverse impacts on future site performance caused by exploratory drifting and testing was weighed against the benefit of the information that might be gained. Initially, the study measured these benefits only in terms of the value of information gained about site suitability. Input from DOE management indicated that the value-of-information

Table 1. Survey of Selected Studies Utilizing Expert Judgment Conducted by the Office of Civilian Radioactive Waste Management

Study/Purpose	Number of Experts[1]	Duration of Task	Results
Site Selection/1986 Environmental Assessments	30	6 mos.	Five sites ranked as basis for nomination for site characterization
ESFAS: evaluate ESF design options per request of regulatory/ overview bodies	200	13 mos.	New design option for ESF selected
CHRBA: determine risk vs. benefit of excavating primary barrier (Calico Hills unit)	50	13 mos.	Benefits of exploration outweigh potential risks to performance of natural barriers
TPT: prioritize site tests to evaluate suitability	100	9 mos.	Highest priority: site characteristics to estimate gaseous releases & unsaturated zone flow and transport processes
ESSE: evaluate status of compliance with DOE Siting Guidelines	14	10 mos.	No disqualifying conditions present; Yucca Mountain suitable for continued characterization
ITE: extend TPT/ESSE results to cover broader reasons for testing	15	9 mos.	Building scientific confidence is dominant factor in ranking site tests

[1] Total number of experts whose judgments were assessed

Key:
CHRBA = Calico Hills Risk/Benefit Analysis
ESF = Exploratory Studies Facility
ESFAS = Exploratory Studies Facility Alternative Study
ESSE = Early Site Suitability Evaluation
ITE = Integrated Test Evaluation
TPT = Test Prioritization Task

approach did not reflect all of the benefits of exploring the Calico Hills; in particular, this approach did not reflect the increase in scientific confidence that would accompany extensive exploration. Therefore, the criteria for evaluating benefits and risks were expanded to include scientific confidence, and the alternatives were re-evaluated.

Subsequently, several studies have been conducted to identify site testing activities most likely to detect unsuitable site conditions and to increase regulatory and scientific confidence, thus aiding management of the site characterization program.

Experience Outside OCRWM

Individuals with experience in the licensing arena raised questions about how licensing boards have reacted to information formally elicited from experts, particularly when a board was unable to interview or cross-examine the experts. Experience with the licensing board for the LaCrosse Boiling Water Reactor shows that elicited expert judgment was not only recognized by the board but, in fact, the board more severely questioned input that was not formally elicited. A second example from the Big Rock Point facility also suggested that after careful review of the credentials of the experts, the board recognized polled expert judgment while raising concerns regarding the uncertainties in non-polled input. The overall conclusion was that elicited multiple-expert judgment has been successfully used and defended in the licensing arena.

There have been numerous analyses involving the structured assessment of expert judgment throughout the federal government. One typical project, an assessment of the acute and chronic risks of ozone exposure, was sponsored by the EPA. After extensive interactions with experts and EPA staff to understand the problem, define the endpoints, and train the experts, a first round of probability assessments was obtained by individual interviews with six experts. The experts then reviewed the judgments obtained before a workshop in which the judgments were discussed among the panel members. Then, a second round of probability assessments was conducted, followed by a second review by the experts. The process was concluded with thorough documentation of the process and its results.

Expert judgment has been broadly used in the Waste Isolation Pilot Plant (WIPP) project to obtain probability distributions for performance assessment, to develop design characteristics for site markers, and to identify uncertainties in hydrologic conditions. Formal procedures have been developed for selecting expert panel members, including scientists from outside the WIPP program. Using these formal methods provides extensive documentation of the rationale and assumptions behind assessed expert judgments, which can be subjected to peer review and reviewed by outside groups.

Other countries also use expert judgment, but somewhat differently from its application in the United States. The European approach presented at the workshop used many experts (i.e. from 10 to 16). The experts were isolated and independent and were provided minimal training.

Elicitation of information was performed on site with each expert. Experts were selected by means of seed variables of known situations to test their expertise, and their opinions were differentially weighted based on their performance on these tests. This approach differs from that of the United States, as put forth by the NRC in NUREG-1150, which employs panels of from four to ten experts who are trained extensively and among whom interaction is promoted. Decision analysts are used to elicit information, and all experts' opinions are weighted equally. Other examples of using expert judgment in foreign programs were shared by representatives from Sweden, the United Kingdom, and Canada.

Following this workshop on the use of expert judgment, on December 16, 1992, at the Advisory Committee on Nuclear Waste (ACNW) meeting in Bethesda, Maryland, the NRC stated that its only interest in DOE's use of expert judgment will be on issues with implications for safety. Licensing phases in which the NRC staff expects to review DOE's use of expert judgment include pre-licensing consultation to ensure the adequacy of data collection; staff review of the license application; review of written evidence, sworn testimony, and cross-examination of witnesses during hearing proceedings; and, the appeal/commission review of the previously established record.

Key Concepts from the Workshop

Strengths of the Structured Use of Expert Judgment

Decision analysis and the structured use of expert judgment help to identify and quantify important factors influencing a decision. Systematically breaking down and analyzing the complexities associated with a decision provides decision-makers with insight into the relative advantages and disadvantages of alternative courses of action. Providing information about the factors influencing a decision and about the differences among alternative outcomes exposes the complexity of the decisions. The effects of uncertainties become measurable, and the risks associated with alternative decisions can be understood. Finally, the costs to reduce uncertainties may be quantified to provide a sound basis for informed decisions about whether further data acquisition or other actions are warranted.

Using expert judgment to develop technical input supporting decisions has other benefits as well. It enables specialists and generalists to work together to define and interpret technical information. Discussions during formal elicitations expose how alternative conceptual models influence the way an expert interprets empirical data. Explicit approaches provide a basis for thorough documentation, which has high value in programs of long duration in which many of the experts may not be available in the future to defend their interpretations.

Limitations in Use of Expert Judgment

Formal techniques are available for reducing bias and obtaining the expert judgments that form the inputs for decision analysis. One limitation of such techniques is the amount of time

required to structure properly and to conduct a thorough expert elicitation effort. Training the experts, ensuring that the problem definition meets the expectations of responsible managers, and conducting the elicitations can be time-consuming and costly. However, when expert judgment is not carefully assessed, the analyses using these judgments may necessarily have to be repeated after peer review. As discussed at the workshop, this occurred in the predecessor analysis to the DOE site evaluation for characterization and in the NRC NUREG-1150 study. In both cases, there were long delays in the project and significant additional costs. In some cases, complexity may be introduced that is later found to be unimportant and that may cause some confusion. Another limitation is the need to be cautious so that decision-makers are not unduly constrained by input from expert elicitations. Managers must be granted the latitude to consider other factors not included in the elicitation process, without being accused of poor management practices.

Approaches used to combine experts' opinions are controversial and could threaten the credibility of the output from a structured elicitation process. Some workshop participants noted that attempting to build consensus may be inadvisable because it could exclude opinions from individuals or groups that reflect highly creative, novel interpretations. However, providing a broad range of alternative opinions to a decision-maker may not be useful in some cases. An additional limitation in using expert panels is the potential for a single, highly opinionated expert to unduly influence other panel members' opinions.

Methods are available for countering the above limitations. Among other things, the speakers addressing this topic stated (1) there is rarely a need to combine experts' opinions, (2) building consensus is not a goal, but defining questions and sharing information often leads to consensus, (3) experts should be chosen to represent diverse viewpoints, (4) sensitivity analysis allows those differences that matter to be identified, and (5) initial, individual assessments are often recommended to avoid domination of a panel by an opinionated expert.

Lessons Learned

Experience suggests that the distinction between decision-aiding and decision-making is important in defining the manner in which structured expert judgment is used to support decisions. However, any decision is likely to be most defensible when important factors are suggested at the beginning and then included explicitly in the analysis. A parallel lesson is that early management involvement in defining the problem to be addressed, as well as remaining attentive to the focus and scope of the activity, are essential to ensuring a useful outcome. The degree of formalism used should depend on the context and complexity of the problem being analyzed. When the issues are complex with many interfaces, reliance on structured assessment techniques is preferred.

Formal use of expert judgment should be viewed as one possible mechanism for codifying, quantifying, and documenting scientific knowledge and bringing relevant scientific knowledge into the decision-making process. Data and expert judgment should not be viewed as interchangeable because data must always be interpreted in light of judgment-based models.

In fact, it is the interpretation of data in a consistent framework that creates the body of scientific understanding. Decision-makers never rely on data alone; therefore, data are never a substitute for expert judgment, and vice versa. Similarly, reliance on expert judgment to build confidence about the validity of computer models and codes is particularly important. Models used in long-term assessments can be validated only partially for a given set of conditions and applications, rather than in some absolute sense, as absolute validation lies outside the realm of scientific inquiry.

Relative to the make-up and training of expert panels, credentials of the experts are often controversial, and multiple experts for each discipline enhance credibility for controversial decisions. It is important to include individuals on a panel who are known to have strongly differing opinions so that uncertainties reflected in these opinions can be represented. It is also important to include experts outside the DOE program. For some problems, it may be useful to include representatives of affected parties. Concerns of those parties thus become known to the experts in a structured format, and important aspects of the total problem then may be consistently identified and addressed. It is important to train panel members to avoid biases and errors of thinking and to enable them to understand the assessment methodology and the manner in which they should respond to elicitations. Experience suggests that experts are willing to work together and that interactions between specialists and generalists are valuable.

Recommendations

The following recommendations are made by the workshop steering committee. The recommendations reflect careful consideration of ideas raised by panelists and other participants and are intended to suggest a broadly based means of educating decision-makers and technical experts, thereby enhancing the quality of decision-making over the course of the OCRWM program.

1. OCRWM should survey the methodology of decision analysis in the United States, as well as internationally, to assess the relative strengths and weaknesses of various approaches. Much of the workshop focused on the formalized use of expert judgment in a decision analysis process, which has evolved through research and application over the past thirty years. Alternative approaches have been suggested by other researchers in the United States and other countries, and many of these approaches have been surveyed and compared with the decision analysis approach. It would be useful to prepare synopses of these alternative methods, to review the evaluations that have been conducted as to their strengths and limitations, and to summarize their overall usefulness in improving the quality of DOE decisions.

2. OCRWM should prepare guidelines that will identify the appropriate role of expert judgment in major program decisions and that will be flexible enough for case-by-case application. The guidelines would address the appropriate degree of formalism in

elicitation and analysis of expert judgment, the appropriate level of modeling and quantitative analysis, and the need for outside expertise and public involvement. These guidelines would allow an approach to choosing an appropriate organizational frame for the decision. Guidelines are intended to help inform OCRWM managers as to the best way to interpret the results of the formal use of expert judgment, especially when it includes quantitative statements of the experts' knowledge and their degree of uncertainty. The plan developed for use of expert judgment by the WIPP Project may be a useful model in developing guidelines for OCRWM.

3. OCRWM should initiate a training program in the elements of quality decision-making and the formal use of expert judgment. Training programs could include the following:

   - an executive seminar in decision quality for OCRWM and contractor upper managers; and
   - a seminar in decision analysis and the formal elicitation of judgment for those who provide expert judgment. DOE should consider the relative merit of using internal (versus external) analysts to conduct elicitation exercises; and, if internal analysts are to be used, the DOE should develop an appropriate training program.

4. The ACNW has suggested that the NRC staff sponsor and participate in an expert judgment exercise during 1993. An elicitation on the topic of climate change is being planned and will be used as a basis for determining if guidance to DOE on the use of expert judgment in performance assessment is needed. Needs for guidance will be evaluated in areas such as selection of experts, methods for minimizing bias, etc. It would be extremely beneficial to OCRWM to have representatives at this exercise to observe this process at each stage. Given the expense of the elicitation, it may be valuable for OCRWM to apply some of the technical judgments to Program decisions related to projected climatic variations.

5. OCRWM should conduct a meeting involving all stakeholders, such as the NRC, the Environmental Protection Agency (EPA), representatives of the nuclear utilities, and the State of Nevada. In this meeting, the stakeholders could

   - explore methods of incorporating expert judgment into the decision-making process;
   - become familiar with each stakeholder's analytic methods and performance-assessment models; and,
   - become familiar with alternative approaches to the use of expert judgment.

6. OCRWM should continue to remain cognizant of the use of expert judgment by other government bodies in regulatory environments (e.g., EPA) to learn of successful applications of expert judgment that might be relevant to the Yucca Mountain Site Characterization Program.

TECHNICAL SUMMARY
OF THE
U.S. DEPARTMENT OF ENERGY'S (DOE'S) WORKSHOP
ON THE USE OF EXPERT JUDGMENT
November 18-20, 1992
Albuquerque, New Mexico

Introduction

In its fourth report to Congress, the Nuclear Waste Technical Review Board (NWTRB) recommended that the U.S. Department of Energy (DOE) hold a workshop to assess expert judgment, and that the DOE and the Nuclear Regulatory Commission (NRC) should agree on how to use expert testimony before the licensing process begins for the Yucca Mountain geologic repository.

Specifically, the NWTRB recommended that DOE see how expert judgment already has been used within the nuclear industry and then make specific recommendations for its use in performance assessments.

The Office of Civilian Radioactive Waste Management (OCRWM) sponsored the workshop. Its stated objective was to examine the appropriate use of expert judgment, both in performance assessments and in enhancing the quality of decisions made by OCRWM. Another objective was to identify the advantages and limitations of using expert judgment.

In addition to keynote speakers, there were four moderated panels discussing the following topics: The Process of Quantifying Expert Judgment; Expert Judgment as a Data Supplement and Expert Judgment in Model Validation; Expert Judgment in Programmatic Decisions; and Industry Experience with Expert Judgment.

Opening Remarks

Dr. John Bartlett, OCRWM Director, opened the program with an overview of the opportunities and incentives to use expert judgement in nuclear waste disposal programs. Although seeking and using expert judgment appears expensive, it can reduce or avoid costs later, Bartlett said. It may significantly reduce the resources needed to acquire data and help to resolve issues in regulatory review. The use of expert judgment also can increase confidence in decisions, both within the industry and with the public, because the process establishes measurable performance goals.

If the 1988 Site Characterization Plan for Yucca Mountain is revised, expert judgment should have a role in that revision, Bartlett said. He noted that the DOE used decision-analysis techniques to select the design of the Exploratory Studies Facility and that expert judgment was used to help rank candidate disposal sites. Expert judgment also can be used to support review activities.

ENCLOSURE 2

Expert judgment is a process that should aid in making decisions but not force them, Bartlett said, and he identified specific uses for the process, such as supporting findings concerning site suitability, assisting with selecting engineered designs, strengthening performance assessments, and building the framework for interacting with regulatory agencies such as the NRC.

Dr. Bartlett noted unresolved issues associated with the use of expert judgment: Under what circumstances would expert judgment be more beneficial than other methods? When would expert judgment strengthen information and support decisions specifically for the nuclear waste disposal programs?

Dr. J. Russell Dyer, Yucca Mountain Site Characterization Project Office, said expert judgment will play an important role in many aspects of the repository program, including: screening events, developing models that characterize the geology and hydrology of the system, assessing parameters, collecting data and making decisions about performance.

The program's applications of expert judgment range from informal to formal, Dyer said. Formal approaches were used for site selection and for the Exploratory Studies Facility Alternatives Study, as well as for the Calico Hills Risk-Benefit Analysis, the Integrated Test Evaluation and the Test Prioritization Task. Less formal approaches were used in the Site Characterization Plan and the seismic design cost-benefit study. Intermediate between formal and informal are peer reviews, technical and design assessments, and the Early Site Suitability Evaluation. Examples of peer and technical reviews that DOE has conducted include the following:

- A peer review of tectonic guidelines in the 1986 Environmental Assessment of Yucca Mountain;
- A peer review of the validity of the Szymanski hypothesis and the adequacy of a planned program for tests needed to study calcite-silica deposits;
- A technical assessment of the potential for faulting near the proposed exploratory shaft; and
- A peer review of the unsaturated zone hydrology program.

Dr. Warner North, of the Nuclear Waste Technical Review Board, stated that expert judgment is used regularly to make decisions in the personal, corporate, and public policy areas. To make well-informed decisions, technical information based on the experience and judgment of people are needed.

When seeking expert judgment, North said, it is important to select experts properly, to understand their stories, to document the basis of their judgments, and to determine how much information is needed to arrive at a decision.

In previous reports to Congress, the Board stressed the DOE's need for peer reviews and recommended that outside experts be used and their judgments documented. The Board also discussed the Department's need to use modeling techniques and the collective judgment of technical experts in assessing performance in certain areas.

Also, the Board told Congress that the DOE needed to refine further its methods for assessing expert judgment, and that the DOE and the NRC should agree on the potential use of experts before the licensing process begins for Yucca Mountain.

In a response, the DOE informed the Board that it plans to preserve the flexibility to define expert judgment or peer review for specific cases when the subjective method may become necessary.

Paul Pomeroy of the Nuclear Regulatory Commission's Advisory Committee on Nuclear Waste was unable to attend the workshop, but he sent a letter which Dr. North delivered. Pomeroy said his comments were his personal opinions. He wrote about the need for the NRC to seek consensus within the technical, political and public communities on an acceptable methodology for seeking and using expert judgment. He also suggested that the legal framework of expert judgment be explored before the licensing process begins.

The keynote address was given by **Dr. Ronald Howard** of Stanford University, who told participants that the question was not whether to use expert judgment, but how to use it.

The questions to be considered are:

- What is a quality decision?
- How can knowledge or judgment be represented?
- What is a defensible decision, and how can it be achieved?

Quality decisions require the balanced, accurate inclusion of expert judgment -- human judgment -- he said. They require a high level of professional competence, careful planning and skillful execution, as well as:

- Appropriate framing of the question.
- Creative alternatives.
- Meaningful, reliable information.
- Clear values and trade-offs.
- Logically correct reasoning.
- Commitment to action.

The first step toward making a quality decision is framing a question correctly in order to get a beneficial answer. Unless the question is properly framed, Howard said, the fact-gathering process can become skewed and the results unusable.

To frame a question well, there must be a clear purpose and defined scope. The process will fail, he said, if the scope is too narrow, if there are unstated assumptions, or if one plunges into the process. Once the question is framed, it is best to develop creative, doable solutions. A failure may occur if there is only one alternative, he said.

The next step is information. Data must be meaningful and reliable, but it should be studied in the context of the limits of what is known. Data counted as reliable are meaningful only when interpreted through models created from the knowledge of experts, he said. Knowledge

can be represented by taking into account all that is currently known, and not what is believed or thought to be true. Knowledge is objective and expressed without bias or belief. Key tools in knowledge-gathering are research, encoding of judgment, and removing bias. Failure modes involve neglecting to obtain important information or ignoring uncertainty.

Once knowledge has been gathered, the team should examine values and trade-offs. Key tools in establishing values and trade-offs are expectations of outside parties and whether the decision is long-term or short-term. A defensible decision will follow based on reliable information, as well as correct logic and creative solutions. After decision criteria have been established, then reasoning begins. The reasoning process should bring together all the knowledge that has been gathered so it can be examined logically and the consequences of each alternative considered. A failure mode is using the wrong logic.

A team effort is necessary to reach a defensible position, and there must be creative, compelling alternatives to whatever decision is reached. After examination and reasoning, a commitment to action will emerge. To have a commitment, the organization must have been involved. Also, there must be credibility and preparation for action.

Howard believes that, in order for any group process to be successful, information must be exchanged regularly between managers and the team doing the work. Whenever appropriate, managers and the team must develop, refine, evaluate and review each other's work.

PANEL I: THE PROCESS OF QUANTIFYING EXPERT JUDGMENT

Systematic Process for Assessing Expert Judgment
by Ralph A. Keeney, University of Southern California

R. Keeney described how expert judgment can be assessed and used beneficially. Experts must be searched out, selected and trained. They should have no apparent conflicts of interest, and they should not be shy about expressing their thoughts. There are two types of experts: specialists and analysts. Specialists have detailed knowledge in their field, while analysts' expertise is in probability.

After experts are selected, they should follow a process that will elicit probabilities using the following steps:

- Refine the issues to identify events and variables for elicitation;
- Train experts for the elicitation;
- Elicit judgments;
- Analyze judgments;
- Resolve differences between judgments;
- Aggregate data; and
- Document and communicate information about the study, including its results.

A good assessment process will have certain characteristics. Before the assessment, the events or variables for which probabilities will be assessed need to be unambiguously defined.

During the assessment, the influence of motivational or cognitive biases should be minimized and questions should be adapted to the experts' thought processes. At the conclusion of the assessment, it should facilitate communication, support documentation, withstand peer review, and minimize the misuse of the experts' judgment.

Assessments can be used to represent the current state of knowledge, to facilitate informed decision-making, to improve communication, to promote learning, and to account for different ranges of interpretations.

Avoiding Probability Assessment Biases
by Lee Merkhofer, Applied Decision Analysis

L. Merkhofer discussed how biases can be avoided in probability assessments.

Biases in probability judgments are systematic, not random, and they usually can be traced to faulty reasoning. Sometimes biases occur when an expert obtains group judgments using aggregate individual probabilities.

Reasoning biases can be overcome. First, the individual must be cognizant of the bias in order to help eliminate it. Second, training and special techniques may help the individual to counteract and to compensate for bias.

Probability encoding is the process used to help ensure that probability judgments are unbiased. Encoding is undertaken between a subject, such as an expert, and an analyst, such as an interviewer. The analyst's job is to note cues and information-processing used by the subject, to identify the specific biases likely to result, to alert the subject to potential biases, to select encoding techniques to minimize and to counteract the biases, and to use validation methods to verify the results.

Tests show that de-biasing works, but more testing is needed. In fact, experience with formal probability assessment and de-biasing techniques indicates that subjects adjust their responses when biases are explained and demonstrated, and that subjects work hard to produce precise estimates.

What If Experts Disagree?
by Peter A. Morris, Applied Decision Analysis, Inc.

Experts are going to disagree, P. Morris said, but consensus is not a requirement. In fact, in measuring opinions, the aim is to describe knowledge completely -- and that often includes uncertainty. In preparing to deal with disagreements, one should set up a process that assesses observable values, encodes what experts do not know, trains experts in probability assessment, uses an experienced elicitor, and identifies all potential sources of uncertainty.

Before attempting to resolve disagreements between experts, the key disagreements may be focused on by building an analysis framework, such as a spreadsheet or an influence diagram, and then performing a sensitivity analysis.

As for aggregating opinions and solving probability disagreements, one may use either a mathematical combination process or a group process, or one may view expert opinion as a data observation, and update the probability assessments based on expert information by using standard Bayesian inference.

In summary, (a) basic issues can be guidelines for designing the approach to mechanical or behavioral aggregation in a specific application, (b) good modeling or science should not be diluted with controversial expert combination methodology. Good problem structure, systematic encoding of expert probabilities, structured communication of the assessment and reasoning among experts are far more important than mechanical aggregation. These factors will provide insight for decision-makers.

Use of Expert Judgment in NRC's Licensing Process
by Daniel J. Fehringer and Margaret Federlein, U.S. Nuclear Regulatory Commission

An NRC licensing decision will be based on a combination of fact and opinion. NRC's licensing process provides a hearing for evaluating facts and opinions. D. Fehringer spoke about the role expert judgment will have in the process, and the compatibility between formal methods for obtaining expert judgment and NRC hearings.

The NRC licensing process has four phases: prelicensing consultation, NRC staff review, a hearing, and the appeal (commission review). Expert judgment may be used in any phase.

In the NRC licensing process, expert judgment is used during the prelicensing consultation to ensure the adequacy of data collection. In reviewing the license application, the NRC looks for the rationale of a decision without needing to know how the rationale was reached. Expert judgment can be used during the hearing, which consists of written evidence, sworn testimony and the cross-examination of witnesses. Expert judgment also can be used during the appeal and NRC's review, if needed. During the appeal, the DOE may ask the Board to reconsider certain issues that were raised during the initial hearing.

During licensing, the NRC has two criteria for admitting evidence: The evidence must establish the expertise of experts, and it must show the relevance of judgments. The judgments of panels are admissible, but this may take the hearing off-track if the weighting method is controversial.

The purpose of the hearing is to identify the correct model for evaluating safety and performance of the repository. Any meaningful projection or relevant information will be considered, he said.

PANEL II, PART A: EXPERT JUDGMENT AS A DATA SUPPLEMENT

Principles Involved

by Milton E. Harr, School of Civil Engineering,
Purdue University, Lafayette, Indiana

Expert judgment is used either to extend existing knowledge or as a substitute for additional data gathering, M. Harr said. He questioned whether there are instances in which expert judgment cannot or should not be used in the place of experimental or testing work. He also asked what constraints could be imposed to ensure that the use of expert judgment is defensible when it either extends existing data or is used instead of additional data.

M. Harr discussed the use of measurements to quantify hypotheses and suggested that scientists should consider the conditions that influenced the development of a hypothesis. All existing theories, laws, formulations, and accepted truths are an amalgamation of the judgments of experts in the past that have survived the test of favorable practice.

There is nothing built exactly as it was designed, he said. In engineering, knowledge is acquired by observing successes and then by making improvements. The expert's function is to formulate a mechanistic model so that predictions can be made about the anticipated performance of things that may not have been done before.

The judgment of experts is valuable in situations with a high degree of uncertainty, as when one is trying to predict the behavior of a system over 10,000 years. Often there are too many possibilities in a given situation, and expert judgment is sought to reduce complexities.

Experience from the 1991 Total System Performance Assessment

by Paul G. Kaplan, Sandia National Laboratories

P. Kaplan discussed the formal application of expert judgment during the Total System Performance Assessment (TSPA) of 1991; the views of the experts that were elicited (in terms of the process, and their view of the products); and the acceptance of this use of expert judgment by the worldwide technical community.

The methods used to elicit and to encode expert judgment were originally developed as an alternative to using expert judgment as a way of formulating the parameters of a model.

Problems exist when there are sparse to nonexistent measurements of the performance assessment parameters from either the site itself or a reasonable analog. There may be a lack of time and trained staff to review the data that are available. The budget and schedule may preclude lengthy or costly approaches. The solution may be a combination of methods.

Kaplan described the experience of the experts elicited during the study. The experts were pleased that the questioning did not call for outrageous speculation. The participation of the performance assessment analyst was an essential element of the process. A graphic display of the probability density function and an explanation of it were essential elements of the

process. Few iterations of the first probability model were needed, and the rapidity of the process surprised everyone.

EPRI Performance Assessment Modeling
by Robert A. Shaw, Electric Power Research Institute

EPRI developed a performance assessment methodology that can be used to characterize a prospective site for a high-level waste repository. Implementation of the methodology demonstrated the process, interactions, and products required for a risk-based evaluation of such a repository. The methodology incorporates uncertainties over a range of technical disciplines while it integrates multiple physical interactions. In addition, it calculates radionuclide concentrations at the site boundary as a function of time, including the likelihood of particular scenarios that lead to radionuclide releases.

Included are uncertainties associated with such calculations. Project teams developed logic trees for performance assessment, reflecting the current uncertainties in scientific techniques, parameters, and data. These were integrated in a software package to calculate released radioactivity for a demonstration. The results were presented as probability distributions of released radioactivity concentrations.

R. Shaw then reviewed a subsequent EPRI project to quantify the uncertainties associated with earthquake and tectonic issues for use in the EPRI high-level waste performance assessment. Another objective of this project was to demonstrate methods for eliciting expert judgment. He described the primary steps in eliciting expert judgment, from selecting specialists to documenting the results. Panelists were chosen for competence and relevant experience in seismology and geology. After elicitation, the specialists discussed key assessments, their interpretations, and the data that drove their thinking. Later, the experts received drafts of elicitation documentation for their correction. Expert assessments were aggregated at the component and final-result levels.

EPRI considered the following as "lessons learned." Training in elicitation methods was found to be very useful. The study participants found that logic trees could be used to express alternative parameter values and their relative credibilities. It became clear that an elicitation was a snapshot of the state of knowledge and therefore was subject to updating. The logic tree format facilitated the elicitation process.

PANEL II, PART B: EXPERT JUDGMENT IN MODEL VALIDATION

Model Validation and Expert Judgment
by Chin-Fu Tsang, Lawrence Berkeley Laboratory

C.-F. Tsang described the INTRAVAL project, which is a study to validate the geosphere transport models for the performance assessment of nuclear waste disposal. The international project began in 1987 and ends in 1993.

There can be no absolute model validation, he said, but there may be practical validation for a particular site, an observable performance measure, a range of parameters, or an estimated range of uncertainties.

Validation should be part of a performance assessment and should be based on an understanding of the major experts and on general scientific reasoning.

For the INTRAVAL project, learned expert judgment (with limits) comes from two types of experts: One has generic scientific knowledge and needs information on the site or issue. The other has site- and issue-specific knowledge but needs more scientific information and needs to study other sites and processes. Project members work on test cases from different countries, and each test case is studied by a number of expert teams that use their own models.

The current state of science is brought into the study by having a broad selection of experts, by eliciting expert judgment, by in-depth discussion of the bases of judgments, and by timely publication of studies in the open literature for scrutiny by the general scientific community.

Use of Expert Judgment in the NRC Low-Level Waste Program
by Matthew W. Kozak, Sandia National Laboratories

M. Kozak proposed participation by both experts and other significant parties in the performance assessment process. Traditionally, developers, regulators, and interveners each reach performance assessment conclusions by different approaches; subsequent conflicts over conclusions lead to litigation.

Interested parties should be included at the beginning of the regulatory decision-making process to reduce conflict. Participatory regulatory decision analysis could lead to initially conservative results, but conservatism can then be reduced by more data collected by focused testing.

Experience from the Waste Isolation Pilot Plant
by Kathleen M. Trauth, Sandia National Laboratories

K. Trauth spoke about the purpose of expert panels set up by the Waste Isolation Pilot Plant (WIPP) program, the procedures the program uses to conduct panel studies, and the results of the panels' work.

Expert judgment panels have been used in situations where experiments both could be and could not be conducted. To date, expert judgment has been used by the WIPP program to obtain interim probability distributions for preliminary performance assessments for the issues of solubility and retardation studies. It has also be used to obtain probability distributions related to the issues of future societies and repository markers. Finally, expert judgment has

been used in arriving at recommendations regarding the issue of uncertainty associated with hydrologic and transport processes in the subsurface pathways at the WIPP.

Procedures for conducting performance assessment by using expert judgment are part of the program's quality assurance process.

The expert panel studies have several basic steps:

- The issue to be addressed by a panel is clearly stated; the panel can later modify the statement.
- Experts are selected by making a broad search. (The scientific community is involved as experts on the panels and in the nomination and selection of panel members.)
- The assessment is implemented in several steps (e.g., by training experts, by providing information to experts).
- Elicitation products (e.g., quantitative probability distributions, rationale) are obtained.
- The assessment (e.g., rationale, assumptions, results) is documented for persons within and outside the organization. This helps to ensure the scientific community is confident in the results and that the results can be defended when decisions are made about the WIPP.

PANEL III: EXPERT JUDGMENT IN PROGRAMMATIC DECISIONS

State of Nevada Experience
by Steven Frishman, State of Nevada

S. Frishman discussed the purpose of the workshop, OCRWM documents (e.g., summaries of the workshop, the ESSE, bias, and the new Energy Policy Act. Mr. Frishman specifically expressed concerns regarding the workshop as an avenue to developing the OCRWM approach to expert judgment.

He specifically requested that recommendations resulting from the workshop be explicitly attributed to the Steering Committee that developed the workshop. He expressed a concern that it might appear that workshop panelists, such as himself, might have concurred on recommendations.

Mr. Frishman also expressed concern with the way expert judgment was used in the ESSE, in that he felt that the scope of the decision-making process was too narrow and did not allow for alternatives, if the currently available data do not support either a suitability or non-suitability finding. J. Boak, YMPO, addressed this concern during the discussion period, in which he pointed out to Mr. Frishman that a finding of "suitable for further characterization" was in fact a recognition of the need for more data.

OCRWM Site Selection Experience
by Tom Isaacs, Office of Civilian Radioactive Waste Management,
U.S. Department of Energy

T. Isaacs discussed repository siting studies that were based on multi-attribute utility analysis (MUA) theory. In response to the Nuclear Waste Policy Act, the Secretary of Energy nominated five sites as suitable for site characterization. The Act also required that the DOE recommend three of the nominated sites to the President as candidate sites for characterization. The DOE formally analyzed the five sites based on information contained in or referenced in the environmental assessments using the MUA theory. The formal analysis was intended to help in the site-recommendation decision by providing insight into the advantages and disadvantages of each site.

The study did not form the whole basis on which a recommendation was made. The methodology did account for the basic considerations specified by the siting guidelines, and it explicitly addressed uncertainties and value judgments.

Mr. Isaacs concluded by noting that even though MUA analyses can be time-consuming and expensive, they provide insight into complex factors that are input to decisions.

Management Perspective on the Use of Expert Judgment in the Development of Geologic Disposal Systems
by Stephan Brocoum,Office of Civilian Radioactive Waste Management,
U.S. Department of Energy

S. Brocoum gave a management perspective of the use of expert judgment to develop geologic waste disposal systems.

OCRWM has applied expert judgment for many purposes: to establish the basis of ranking candidate repository sites, to nominate and to recommend sites for characterization, to evaluate alternative design options for the exploratory studies facility and the potential repository, to evaluate the risks versus the benefits of characterization strategies for the Calico Hills unit, to evaluate priorities for site characterization studies, and to evaluate the suitability of a potential repository site against the technical criteria in siting guidelines.

Past expert judgment studies by the OCRWM afford these insights:

- A formal analysis cannot address every aspect of a decision; thus its results will not or should not form the sole basis of that decision.
- Some studies for the repository program have involved the use of expert judgment and formal elicitation methods; some of these studies tended to focus on decision making as a goal rather than on the goal of providing information to aid managers who are making decisions.
- It is important to define clearly the focus, objectives, and factors for consideration in an evaluation in order to ensure that the results will be useful to decision-makers.

- Strong leadership in an expert judgment study is needed to remain focussed on the objectives established by management and to obtain useful results in a timely and cost-effective manner.
- The selection and makeup of expert panels is crucial; it is better to have multiple experts in each discipline.
- The technical credibility and independence of the experts are important.

A number of lessons about using expert judgment have been learned. The results of using expert judgment should not be viewed as providing decisions but as providing information on technical issues for consideration by management in making decisions. Further, the results of expert judgment should not be considered as a way to provide or to needlessly constrain management decisions. Managers need to understand the bases of decisions and to be able to explain their decisions to external parties (e.g., the public). The process of formally eliciting expert judgment needs to be systematic, open to scrutiny, and easily understood. The bases of expert judgments (e.g., data, assumptions, uncertainties) must be articulated.

Lessons Learned from Past Experience in the Use of Expert Judgment
by Leon Reiter, Staff, Nuclear Waste Technical Review Board

L. Reiter discussed the use of expert judgment during hearings held by the NRC concerning two reactors.

The NRC has always used expert judgment in various ways, either formal or informal, deterministic or probabilistic with single or multiple experts.

Reiter discussed in detail the Systematic Evaluation Program from 1979 to 1981 and studies for hearings on the LaCrosse Boiling Water Reactor (LBP-81-7) and the Big Point Reactor (LBP-84-32). In these studies, elicited multiple-expert judgment was used in several cases, and the use of it was successfully defended in a licensing arena.

The qualifications and diverse backgrounds of the experts were important. Witnesses had to defend their methodological assumptions and to assess the effects of developments such as new earthquakes. Other studies and supporting simple arguments were important. The NRC was comfortable with the elicited expert judgment in an uncertain area of science.

PANEL IV: INDUSTRY EXPERIENCE WITH EXPERT JUDGMENT

Eastern U.S. Probabilistic Seismic Hazard Study
by Robin K. McGuire, Risk Engineering, Inc.

R. McGuire described a seismology study sponsored by the Seismic Owners Group (SOG) and the Electric Power Research Institute (EPRI).

The objectives of the study were:

- To evaluate the specific issue of the 1982 U.S. Geological Survey position on the Charleston earthquake, which had a 7.5-7.7 magnitude;
- To evaluate the general issue of possible large earthquakes elsewhere in the Eastern United States (EUS);
- To provide a comprehensive database of seismicity in the EUS for subsequent use; and
- To develop a methodology for seismic hazard assessment at EUS nuclear plant sites that includes consideration of possible large earthquakes in order to evaluate the potential effect, if any, on nuclear plants.

Expert teams were used and workshops were held to discuss tectonic processes and crustal stresses, the tectonic framework and seismic sources, and seismicity parameters. Workshop participants wrote reports on scientific data presentation, deterministic models of large EUS earthquakes, probabilistic assessments (i.e., models) of possible large earthquakes throughout the EUS, a methodology for seismic hazard assessment at EUS plants, and quality-assured computer code for seismic hazard calculations. Additionally, workshops were held to present the results of this study and for technology transfer.

The project results can be defended because a wide range of expertise was used, fundamental data were available for review, and the bases of expert interpretations were documented.

Reviewers were observers in the study.

McGuire advised people who attempt to extract subjective opinion from experts to:

- Use multi-discipline teams of experts rather than individual experts, and require consensus within each team;
- Use a structured, stepwise approach that reaches consensus and approval at intermediate stages;
- Develop a procedure that complies with fundamental earth science principles;
- Represent quantitative probability estimates as the documentation of scientific judgment, not as a substitute for that judgment;
- Allow enough time for definitions, differences, and objections to be resolved on a scientific level;
- Provide databases for interpretations to all teams;
- Require the justification of interpretations against data;
- Promote communication among teams to eliminate any lack of information and to give interim feedback on preliminary results; and
- Put scientists and engineers in lead roles, not in the subjective-probability-analyst role.

Legal Aspects of NRC Licensing Hearings
by J. Michael McGarry, III, Winston and Strawn, Washington, D.C.

J. M. McGarry discussed legal aspects of NRC licensing proceedings, focussing on the NRC's experience with the use of expert judgment. According to McGarry, how the NRC has used expert judgment in the past predicts how it will use expert judgment in evaluating DOE's application for a license to construct and to operate the high-level waste repository and the monitored retrievable storage (MRS) facilities.

The construction and operation of the repository poses uncertainties, and the NRC will deal with them. Its regulations require the NRC to rely upon the concept of reasonable assurance when considering the uncertainties of projects such as these.

Regulations clearly consider that the NRC fact-finders in the repository licensing proceeding will face gaps in knowledge, and that they will reach a conclusion on the ability to license in the face of those uncertainties.

McGarry also stated that when there are gaps in the available scientific or technical data, the NRC licensing boards must use their expert judgment to make the assumptions necessary to reach a licensing decision. This regulatory judgment is often based in part on the technical judgment of experts who have testified in the proceeding.

Expert Judgment in EPA Health Risk Assessment
by Robert L. Winkler, U.S. Environmental Protection Agency

The Office of Air Quality Planning and Standards (OAQPS) of the U.S. Environmental Protection Agency used expert judgment in a study concerning the effects of chronic ozone exposure on human health. The OAQPS uses the results of expert judgment studies for information, not for making decisions.

EPA undertook this probability assessment, because it is concerned with the possible effects of chronic ozone exposure, particularly irreversible lung injury or lung disease. Experiments in which animals had been exposed to ozone had been performed by the time this assessment began, but comparable data on human exposure were unavailable.

Experts were selected based on their expertise and the need to have the scientific community represented. They reviewed background materials, such as information on exposure conditions and on the groups at risk, and the protocol.

During the study, OAQPS staff met with the experts. The staff prepared the experts for the probability assessment by explaining to the experts the reasons for the questions that would be asked and the importance of the answers. The staff also reviewed the protocol and other background information with the experts and gave them time to study the information. The staff trained experts in probability assessment methods and elicited qualitative judgments from the experts; the answers were documented. The staff then evaluated the experts' judgments and returned the documentation to each expert for his or her confirmation or revision.

The assessment process was documented, from the development of the protocol to the writing of the final report. During the study, there was a workshop on chronic risk assessment,

during which the experts and other participants discussed the qualitative judgments, issues, the probability assessment itself, and research needs.

R. Winkler stressed the value of discussing the probabilities, implied results, and other issues with the experts and of allowing the experts to revise their judgments. He explained the importance of managing the assessment process and controlling costs.

Use of Expert Judgment in the Show-Cause Licensing Proceeding for the Restart of the Vallecitos-General Electric Test Reactor
by Robert E. Jackson, Roy F. Weston, Inc.

R. Jackson discussed the use of expert judgment as testimony in a show-cause licensing proceeding to restart Vallecitos General Electric test reactor (GETR). The GETR is a 50-MW thermal test reactor that has been used to produce radioisotopes and to test radioactive materials. The facility produced technetium 99 used in pharmaceuticals for blood clotting and other medical purposes.

While considering the application to renew the license to operate the GETR, the NRC read a report written by the USGS staff in 1954 that said the Verona fault was within 200 feet of the GETR. The NRC concluded that vibratory ground motion at the site was due either to the Verona fault or to the nearby Calaveras fault, or both. The NRC was concerned that an earthquake of magnitude 6 to 6.5 on the Verona fault would cause significant offsets and acceleration.

After visiting the site, the NRC threatened suspending the facility's operating license and shutting down the GETR. At the NRC's request, the Atomic Safety and Licensing Board (ASLB) held hearings.

The NRC agreed with GE's expert testimony that the postulated Verona fault would not surface beneath the GETR and would be deflected around it. The NRC, the Advisory Committee on Reactor Safety, ASLB, and Atomic Licensing Appeal Board accepted probabilistic analyses of geologic information on the fault offset as well as deterministic analyses. The structures, systems, and components of the GETR that were important to safety had to be modified to mitigate the effects of fault offset and ground motion.

An International Comparison of Approaches to Expert Judgment Elicitation
by Stephen C. Hora, University of Hawaii at Hilo

S. Hora spoke of a European and American expert judgment project designed to quantify consequence codes for releases from nuclear power plants. A project goal was to develop probability distributions for certain parameters and consequence models in such a way that the findings of a given panel of experts would suffice for two different consequence models, COSYMA (the "European" EEC model) and MACCS (the "American" NRC model).

The elicitation issues during this expert judgment project were dispersion and deposition, plume rise, behavior of deposited material, internal dosimetry, early and late health effects, and food chain parameters.

The European protocol has isolated experts, provides minimal training, and has seed variables, used to check the truth of statements. Additionally, three points on a distribution were elicited, and experts' judgments are weighted based on their performance in answering questions. The American protocol has panels of four to ten experts, provides extensive training, promotes interaction among experts, uses decision analysis to elicit, decomposes assessments, allows for feedback after an expert's information is written up, and equally weights the judgments of all experts.

Several principles of probability elicitation were derived during this study.

- The estimates of consequences and associated uncertainties can be significantly affected by analyzing issues using expert opinion;
- Assessments should be limited to issues for which alternative sources of information (e.g., experimental or observational data or validated computer models) are not available or for which multiple sources of information offer conflicting or incomplete evidence;
- Experts should be required to respond only to questions about physically measurable quantities; and
- Issues should be presented unambiguously to the experts to avoid getting preconditioned or biased responses.

Closing Remarks

In his closing remarks, Dr. Dyer said that a dialogue has now been opened that will continue and that this workshop should prompt educated decisions to be made about the use of expert judgment. He added that by using the methods discussed in the workshop, the quantification of uncertainty could be addressed more effectively. Dr. Dyer supported the commitment to use formal decision analysis by the Yucca Mountain Site Characterization Project Office.

Dr. Bartlett's closing address began with his stating that, as a result of the workshop, he now feels more open to the use of expert judgment in making management decisions. He suggested that the DOE hold a Director's Forum on how expert judgment could be applied by the DOE, especially as it relates to building public confidence. Dr. Bartlett said that although it is important to "frame" the issue, this may be extremely difficult in the Yucca Mountain Project, given the high uncertainty remaining for some of the scientific parameters. Dr. Bartlett stated a concern about the potential for creating vulnerability in the public and regulatory arenas if consensus cannot be achieved for a given issue using formal expert judgment methods. He said that the decision of whether or not to use formal decision analysis should be based on the value-added criteria, which must include time and cost considerations as well as the important intangible benefit of building public confidence. Dr. Bartlett posed the questions of what unusual difficulties the OCRWM program may face in

demonstrating compliance and how the use of expert judgment might help to resolve those difficulties.

In his closing remarks, Dr. North praised the workshop enthusiastically. He went on to say that he agreed with most of what was said. However, Dr. North stated that the DOE has room for improvement and is still on the steep part of the learning curve regarding the use of expert judgment. He continued that the lack of teamwork is the most important area for DOE to address. He also pointed out that it is important for DOE to prepare for NRC licensing. Dr. North added that improving credibility and clarity should be job number one for the DOE. He said that to achieve credibility, the public must believe either the process or the people. Dr. North concluded that there is often a tradeoff between common sense and formalism, but the project needs to have both and can get both through continued practice.

AGENDA
EXPERT JUDGMENT WORKSHOP
Albuquerque, NM
November 18-20, 1992

Wednesday, November 18, 1992

8:00	Introductory Remarks	Dr. John Bartlett, DOE/OCRWM
8:20	Overview	Dr. Russell Dyer, DOE/YMP
9:00	NWTRB Remarks	Dr. D. Warner North, NWTRB
9:30	The Role of Expert Judgment in Creating Quality Decisions	Dr. Ronald Howard, Stanford U.
10:30	BREAK	

PANEL I: THE PROCESS OF QUANTIFYING EXPERT JUDGMENT
Moderator: Dr. Bruce Judd, Decision Analysis Co.

10:45	Systematic Process for Assessing Expert Judgment	Dr. Ralph Keeney, USC
11:25	Open Discussion	
11:35	Avoiding Probability Assessment Biases	Dr. Miley Merkhofer, Applied Decision Analysis, Inc.
12:10	Open Discussion	
12:20	LUNCH	
1:35	What if Experts Disagree?	Dr. Peter Morris, Applied Decision Analysis, Inc.
2:10	Open Discussion	
2:20	Panel Discussion: Questions	Dr. Bruce Judd

1. If the topic were changed from "using expert judgment" to "using human knowledge," how would it affect anything said at this workshop?
2. Are there situations when expert judgment (human knowledge) is not used?
3. On what basis is the level of detail and formality for incorporating expert judgment in performance assessments or in decision-making chosen?
4. When is consensus necessary and appropriate?
5. Should expert judgments be weighted; if so, how could this be done?
6. How are alternative models handled?

ENCLOSURE 3

3:20	BREAK	
4:05	NRC Comments on Use of Expert Judgment	Dan Fehringer/Margaret Federlein, NRC
4:20	Open Discussion	

PANEL II, PART A: EXPERT JUDGMENT AS A DATA SUPPLEMENT
Moderator: Dr. James Duguid, CRWMS/M&O

4:30	Principles Involved	Dr. Milton Harr, Purdue U.
4:50	Open Discussion	
5:00	Experience from Total System Performance Assessment	Paul Kaplan, SNL
5:20	Open Discussion	
5:30	EPRI Performance Assessment Modeling	Dr. Robert Shaw, EPRI
5:50	Open Discussion	
6:00	ADJOURN	

Thursday, November 19, 1992

PANEL II, PART B: EXPERT JUDGMENT IN MODEL VALIDATION
Moderator: Dr. Abraham Van Luik, CRWMS/M&O

8:00	Overview	Dr. Chin Fu Tsang, LBL
8:20	Open Discussion	
8:30	Experience NRC from Low-Level Waste Program	Dr. Matthew Kozak, SNL
8:50	Open Discussion	
9:00	Experience from Waste Isolation Pilot Project	Dr. Katherine Trauth, SNL
9:20	Open Discussion	
9:30	Panel Discussion: Questions	Dr. Abraham Van Luik

1. What fundamentals are involved when expert judgment is being used either to extend existing data/knowledge or as a substitute for additional data gathering?
2. What constraints should be imposed to ensure that the use of expert judgment is defensible when it either extends existing data or is used in lieu of additional data gathering?
3. How may expert judgment be used in the evaluation of the "validity" of long-term and long-distance predictions of geologic processes?
4. Can expert judgment add to the limited confidence that can be obtained from short-term/short-distance testing in support of long-term/long-distance predictions?
5. How has the quantitative use of expert judgment been used to develop and/or to establish confidence in performance assessment modeling?

10:30 BREAK

PANEL III: EXPERT JUDGMENT IN PROGRAMMATIC DECISIONS
Moderator: Dr. Jean Younker, CRWMS/M&O

10:45	State of Nevada Experience	Steven Frischman, State of Nevada
11:00	Open Discussion	
11:10	OCRWM Site-Selection Experience	Dr. Thomas Isaacs, DOE/OCRWM
11:25	Open Discussion	

11:35	Views on Use of Expert Judgment in in Programmatic Decisions	Dr. Paul Pomeroy, ACNW
11:50	Open Discussion	
12:00	LUNCH	
1:15	DOE Management Perspective on the Use of Expert Judgment	Dr. Steve Brocoum, DOE/OCRWM
1:30	Open Discussion	
1:40	Lessons Learned from Past Experience with Use of Expert Judgment	Dr. Leon Reiter, NWTRB
1:55	Open Discussion	
2:05	Panel Discussion: Questions	Dr. Jean Younker

1. Does explicit incorporation of expert judgment in programmatic decisions lead to more defensible decisions?
2. What types of implicit use of expert judgment in programmatic decision-making is most prevalent in your experience?
3. Are you aware of cases where explicit use of expert judgment in programmatic decisions has made a difference in the outcome?

PANEL IV: INDUSTRY EXPERIENCE WITH EXPERT JUDGMENT
Moderator: Dr. Robert Shaw, EPRI

3:00	Eastern United States Seismic Hazards	Dr. Robin McGuire, Risk Engineering, Inc
3:15	Open Discussion	
3:25	Legal Aspects of Licensing Hearings	Michael McGarry, Winston & Strawn
3:40	Open Discussion	
3:50	BREAK	
4:05	New Production Reactor Seismic Design	Dr. John Savy/LLNL
4:15	Open Discussion	
4:25	Vallecitos Reactor Licensing	Dr. Robert Jackson, Roy F. Weston, Inc.
4:40	Open Discussion	
4:50	International Programs	Dr. Steven Hora, Univ. of Hawaii
5:05	Open Discussion	

5:15 Panel Discussion: Questions Dr. Robert Shaw/EPRI

1. What does experience tell us about the use and application of expert judgment? Evaluate the process you used.
2. Evaluate the decision(s) reached as a result of the expert judgment process you used.
3. What are the strong/weak points of expert judgment as it is currently compiled and used?
4. How can expert judgment best be elicited to produce acceptance in the regulatory arena?
5. What makes expert judgment difficult for regulators to accept? How could the process be conducted or the results be formulated to make expert judgment more acceptable?
6. How can expert judgment panel selection be accomplished objectively? Will this influence the degree to which results are accepted in the regulatory area? How?

6:15 ADJOURN

Friday, November 20, 1992

WORKING GROUP
Moderator: Dr. Ardyth Simmons, DOE/YMP

8:00	Panel I Summary	Dr. Bruce Judd
8:30	Panel II Summary	Dr. Abraham Van Luik/ Dr. James Duguid
9:00	Panel III Summary	Dr. Jean Younker
9:30	Panel IV Summary	Dr. Robert Shaw
10:00	BREAK	
10:15	Roundtable and Open Discussion	Dr. Ardyth Simmons
11:15	Closing Remarks	Dr. Russell Dyer
11:30	Closing Remarks	Dr. John Bartlett
12:00	Closing Remarks	Dr. D. Warner North
12:10	ADJOURN MEETING	
12:30	Convene Working Group (Lunch to be provided to working group participants)	Moderators and Steering Committee
4:00	Adjourn Working Group	

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