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A Formal Expert Judgment Procedure for Performance Assessments of the Waste Isolation Pilot Plant

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A FORMAL EXPERT JUDGMENT PROCEDURE FOR PERFORMANCE ASSESSMENTS OF THE WASTE ISOLATION PILOT PLANT

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ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is an experimental facility located in southeastern New Mexico. It has been designed to determine the feasibility of the geologic disposal of defense-generated transuranic waste in a deep bedded-salt formation. The WIPP was also designed for disposal and will operate in that capacity if approved. The WIPP Performance Assessment Department at Sandia National Laboratories has been conducting analyses to assess the long-term performance of the WIPP. These analyses sometimes require the use of expert judgment. This Department has convened several expert-judgment panels and from that experience has developed an internal quality-assurance procedure to guide the formal elicitation of expert judgment. This protocol is based on the principles found in the decision-analysis literature.

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PREFACE

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I. INTRODUCTION

The purpose of this paper is to discuss some of the lessons learned about the elicitation of expert judgment. These lessons are presented in the context of the Waste Isolation Pilot Plant (WIPP) Performance Assessment Department's experience with analyses of a proposed nuclear waste disposal facility.

The goal of nuclear-waste disposal is to isolate the waste for a sufficiently long period of time so that the radioactivity does not pose an unacceptable threat to humans. Since the beginning of the nuclear age, defense-related projects have generated waste contaminated with radionuclides as a byproduct of the development, manufacture, and decommissioning of nuclear devices. Some of this waste contains radionuclides heavier than uranium. This waste is referred to as transuranic (TRU) waste.

The WIPP, which is located in southeastern New Mexico, contains a test facility for investigating whether the characteristics of the location are suitable for the disposal of TRU waste. The WIPP, also a proposed disposal facility, will be located at a depth of 2,150 feet and within a bedded-salt unit (the Salado Formation). If the WIPP can be shown to comply with the appropriate federal regulations, a section of the facility not used for testing will become a disposal facility for the TRU waste.

A. The EPA Standard

One of the federal regulations with which the WIPP must comply is the U.S. Environmental Protection Agency's (EPA's) *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR 191),^{1,2} hereinafter referred to as the Standard. The Containment Requirements within the Standard set probabilistic performance requirements that are to be addressed by conducting performance assessments. These

assessments are to consider the 10,000 years after closure of the disposal facility. The Standard also mandates the implementation of Assurance Requirements to account for some of the uncertainty associated with performance assessments covering 10,000 years. These performance assessments are 10,000-year simulations of performance carried out on computers using models of the disposal system. Sandia National Laboratories (SNL) is the U.S. Department of Energy's scientific advisor for the WIPP and is conducting the performance assessments.

B. Experience with Expert Panels

Several formal expert-judgment panels have been convened to support the WIPP Project, both in conducting performance assessments and in addressing the Assurance Requirements. The first panel, the Future Human-Intrusion Panel³ (Futures Panel), was convened to identify possible modes of human intrusion over the 10,000-year regulatory period and to estimate the frequencies of such intrusions. The second panel, the Marker-Development Panel⁴ (Markers Panel) was convened to address the need for permanent, passive markers to communicate the location and nature of the wastes proposed to be disposed of in the WIPP. The requirement to mark the disposal site is found in the Assurance Requirements. In addition, the effectiveness of markers in deterring inadvertent human intrusion into the WIPP is pertinent to the Containment Requirements. Because human intrusion would create potential pathways for radionuclides to reach the accessible environment, the Standard states that credit may be taken for such deterrence in the calculations.

Two additional panels were convened to supply interim probability distributions for parameters used in the performance assessments. The Source Term Expert Panel⁵ (STEP) provided probability distribution functions (pdfs) of the concentrations of radionuclides that might be expected in brines within the WIPP disposal rooms, given the potential environmental conditions within the rooms. A pdf represents the values that a fixed, but unknown,

variable may be expected to assume and the corresponding probabilities of occurrence of the values. The Retardation Expert Panel⁵ (REP) provided pdfs of the distribution coefficients (K_d s) that may be expected in a water-bearing formation above the repository level, the Culebra Dolomite, that may act as a pathway for radionuclide transport to the accessible environment. These K_d s indicate the extent to which the natural properties of the Culebra Dolomite retard the transport of radionuclides in ground water.

II. EXPERT JUDGMENT

An incomplete understanding of expert judgment may cause some individuals to question the appropriateness of its use in the context of performance assessments for a nuclear waste disposal system.

Professional judgment is implicit in scientific investigations. The development of a conceptual model to describe a natural phenomenon requires judgment to examine the current state of knowledge and to produce a coherent model of the behavior of a natural system. Judgment is required in developing mathematical and computational models to represent conceptual models. Before data are ever collected from an experiment, judgment is used in developing the hypothesis to be evaluated, in establishing the experimental conditions, and in selecting data-collection methods and equipment. Experimental data require interpretation for appropriate use in computational models.

Expert judgment is the best professional opinion of experts in a particular field. It is used to synthesize what is known (existing data) to provide the required information for a particular application. Judgment explicitly elicited from an expert panel is not a substitute for measured data, but is used to examine and synthesize whatever data exist (however abundant or sparse, under whatever experimental conditions they were collected) to provide the required information. Measured data from

appropriate, practical experiments performed in a timely manner are always preferred. The extent to which directly applicable data exist and to which a phenomenon is understood dictates the extent to which judgment must be used to provide the required information. Elicited expert judgment may be appropriate and necessary where data are sparse or nonexistent, where data were collected for other applications, or where data are conflicting. For subjects where a great deal of directly applicable data exist and the phenomenon is well understood, elicited judgment may not be required to provide the necessary information (e.g., data may be analyzed by statistical techniques). The appropriate use of elicited expert judgment must be evaluated on a case-by-case basis and is driven by the individual circumstances.

Data may be collected through measurements or observations, under experimental or natural conditions. Information may be defined as data interpreted and used for a specific application. Categorical exclusion from consideration of all pertinent data collected for other purposes would not be appropriate. Data from other studies should be evaluated for applicability, and excluded or considered as appropriate.

When alternative sources of information--models and data--are available but conflict, the elicited judgments of experts may be the preferred method for integrating the data into a single probability distribution. Experts may be able to assess the uncertainty inherent in the various sources of information and, additionally, may be able to make adjustments to account for biases in the data. Expert elicitation, therefore, may provide a "calibrating" mechanism to account for differences in applications, environments, and other factors.

As an example, many data exist about the durability of monuments over time--how they have weathered natural and human assaults. All of this should be evaluated in designing the required markers for a repository, even though the data were not collected in a

form that will directly indicate marker types. It is appropriate to elicit expert judgment to evaluate the existing data collected for archaeological or materials science purposes, and synthesize these data to develop design guidelines and estimate durability.

Another example is the need for a probability distribution of a parameter for use in the probabilistic calculations for preliminary performance assessments. Data exist on the solubility of particular radionuclides under specific environmental conditions. The information required is a probability distribution of the solubility of a radionuclide when there is uncertainty about the specific environmental conditions that will exist in the repository over time. An examination of all the available data may allow judgments about the impact that various uncertainties will have on the solubility.

Concerns have been expressed regarding the interpretations of the findings of the experts who examined future societies.³ A concern is that no one can tell the future. This is, of course, correct. What is not properly understood, however, is that the experts' role is not to identify what the future will be but to identify a variety of alternative futures that might be applied to efforts to develop effective institutional controls. A discussion of how frequently future societies might be taking actions that could intrude upon the WIPP can be utilized to determine how to implement EPA's guidance that exploratory drilling for resources is the most severe intrusive event that must be examined for compliance.

The evaluation of data and information for the purpose of policy and decision making has led to the development of formal methods for the collection of expert judgment through the elicitation of probabilities.^{6,7,8,9} These techniques have been applied to acquire information for use in the performance assessment of the WIPP through a formal "protocol" developed and implemented by the WIPP Performance Assessment Department at Sandia National Laboratories.¹⁰ This

protocol will be called the Sandia/WIPP protocol. The techniques invoked by the protocol are those described in the literature, while the actual implementation of the techniques is conducted in a fashion that responds to the particular requirements of a nuclear-waste disposal project.

III. WHEN FORMAL EXPERT JUDGMENT IS USED FOR THE WIPP PROJECT

Informal expert judgments are used in most stages of performance assessments. A formal approach to the use of expert judgment is required when (1) an issue is of particular interest or sensitivity to policy makers, scientific groups, or the public, or (2) previous assessments have shown a particular parameter to greatly influence the results; and (i) alternate sources of information, data, and models are currently unavailable or are not practical to obtain, or (ii) the required data or information are not obtainable by any means other than expert judgment (e.g., future states of society).

The issues selected by the previous criteria should be addressed by an external panel of experts in consultation with staff scientists. Acceptance by the public and oversight groups is enhanced when independent experts arrive at positions even though the same judgments might be rendered by staff scientists also involved in the process. This trust and acceptance is an important aspect of expert panels.

IV. THE IMPORTANCE OF AN ESTABLISHED PROCEDURE

A documented, established procedure for eliciting expert judgment is an aid both in maintaining the quality of the process and in supporting internal and external reviews of the process.

The Sandia/WIPP protocol was developed from a procedure that had been developed and reported in the

decision analysis literature and with the cooperation/input from a consultant from the discipline of decision analysis. Through several expert judgment panels, the Sandia Performance Assessment Department gained insights into the topics that were important to address in an internal procedure in order to maintain the quality of the process. The procedure can continue to develop over time, as warranted, with changes implemented in subsequent uses of expert judgment.

The organized, documented procedure allows reviewers to reconstruct the logic and the events involved in the use of expert judgment. The availability of such documentation supports a better understanding and acceptance of what was undertaken. In addition, discussions in terms of principles rather than in terms of the individual outcomes are more efficient.

V. ISSUE STATEMENT

The development of a comprehensive but concise issue statement is fundamental to the successful elicitation of expert judgment. The issue statement precisely defines what must be addressed by the expert(s) and the format in which the judgment(s) must be presented. The development of the issue statement also plays a major role in identifying the types of experts and/or the fields of expertise to be included for eliciting expert judgment.

Issue statements are difficult to develop, and they are evolutionary. Words and phrases can mean different things to different individuals. In addition, the components of an issue may be different for persons with different perspectives. Because of possible differences in interpretations, draft issue statements are best developed as a collaborative effort rather than by a single individual. Numerous iterations of the issue statement are the rule rather than the exception.

The evolutionary nature of issue-statement development continues once the statement is presented to

the experts. Experts will introduce additional perspectives and identify additional ambiguities in wording, issue decomposition, and response formats that must be resolved before unambiguous expert judgments can be obtained. The variety of perspectives and ambiguities are especially acute for multidisciplinary panels.

For example, the Markers Panel modified the issue statement by eliminating the partial focus on individual markers, and emphasizing the interdependent-systems approach they believed was crucial to long-term communication of information. The STEP also modified their issue statement after judging that sufficient related data did not exist to create pdfs for the concentrations of colloids in brine.

VI. EXPERT IDENTIFICATION AND SELECTION

A. Criteria for Selection

Careful selection of the expert-panel members will ensure that a panel is convened that includes individuals with the appropriate qualifications and a willingness to participate fully in the expert-judgment process.

The issue(s) to be addressed by the panel determine the disciplines that must be represented, as well as the experience that is required. This connection between the issues and the disciplines is operative whether a panel is being selected from among chemists to provide required information about the solubility of radionuclides in brines or whether a panel is being formed from individuals in the disparate disciplines pertinent to the development of communication markers for a repository. In general, the criteria for inclusion as a nominee for an expert judgment panel revolve around recognized expertise in the area(s) pertinent to the issue. Obtaining an appropriate list of nominees may require different strategies depending on the issue to be addressed. For the STEP, initial nominations were sought from scientists at

Sandia, members of a Performance Assessment Peer Review Panel, and members of the National Academy of Sciences WIPP Review Panel. For the Futures and Markers Panels, the areas of expertise thought to be pertinent were so large (the issues of future societies and markers), that the Project solicited nominations from professional societies, technical journals, government organizations, and public interest groups. Initial nominees also nominated other individuals with whose expertise they were familiar.

It is also important to nominate individuals representing the spectrum of thought on a topic, if there may be different approaches or paradigms. As an example, when soliciting nominees for the Futures and Markers Panels, organizations such as the League of Women Voters, the Sierra Club, and other environmental groups were solicited for nominees in order that individuals with potentially diverse or opposing views could be considered for inclusion. For example, the Futures Panel included an individual from the Natural Resources Defense Council (NRDC), who was lead attorney in *NRDC v. EPA*,¹¹ the 1987 court case that resulted in the remand of the Standard. Individuals with differing views on the appropriateness of nuclear weapons and nuclear power were also represented on the Markers Panel.

Also required for an effective panel are members who understand and accept the constraints of the expert-judgment elicitation process. A constraint may be considered to be an aspect of the process with which some individuals may not be totally comfortable, but which is required. For example, an expert may not be comfortable in making judgments based on incomplete data, but the information may be necessary even if the experiments are still underway or cannot completely answer all questions. Another example of a constraint is that while an expert may not be familiar with expressing his or her judgments as probabilities or pdfs, the Standard requires a probabilistic performance assessment. The members of the

REP recognized the incompleteness of the existing data (existing data were produced from batch rather than field experiments,¹² additional experiments were being planned, etc.) but worked to address the issue with the available data because interim pdfs for K_d s were needed for the preliminary performance assessments. Similarly, a few members of the Futures and Markers Panels had reservations about the advisability of nuclear weapons and nuclear power, and about the appropriateness of EPA regulations, yet they worked diligently to address the issues as best they could.

B. Selection Advisory Committee

A selection advisory committee (SAC) can serve the process by ranking the qualifications of the nominees and suggesting a final composition that covers all the required disciplines and subdisciplines. Whenever possible, the pertinent disciplines should be represented on the SAC. A SAC is suggested not only to establish the highest quality panel, but also for the independence they bring to the process.

VII. TRAINING

Training is provided for the experts in two distinct areas so that the panel members have access to the information necessary to perform their tasks. The first area of training consists of a series of presentations related to the topics of the WIPP, the EPA Standard, performance assessments, and previous and ongoing characterization studies. The second area of training consists of presentations relating to the topic of expert judgment in general and to the elicitation of expert judgments.

A. Orientation to the Project

These presentations related specifically to the Project set the stage for the context in which the expert judgment is required. It is important that the panel

members understand the requirements of the Standard for probabilistic performance assessments and thus the need for pdfs for parameter values. Such training can also indicate why certain parameters are of greater importance and are subjected to the formal expert-judgment elicitation process. Training also explains the need to address inadvertent human intrusion into the WIPP and requirements for long-term passive markers for the repository.

Training is provided by staff members who are available to answer questions during an initial informational meeting and during the subsequent panel deliberations. This interaction ensures that all applicable Project data are available to the panel. The insights provided by the training can feed back into the development of the issue statement.

The training for the Futures and Markers Panels included a tour of the WIPP and surrounding area.

B. Elicitation Training

The elicitation process is more than just the application of probability assessment tools to the judgments of experts. The experts must prepare and be prepared for the experience. Often, experts in a field such as a physical science may not be effective in expressing their beliefs in the form of probabilities or pdfs.^{13,14} Training the experts in forming these judgments is an important step in the Sandia/WIPP protocol.

This training has multiple objectives. One is previewing the process including how the experts' judgments will be used. Other objectives are to instill confidence in the experts not only so that they can express beliefs as probabilities and pdfs, but also because lack of confidence in the process may undermine the effort.

Experts may object to the formal elicitation and encoding of judgments into probabilities and pdfs because

they believe "opinion" is being substituted for "objective" scientific research. However, the experts' role is not creating knowledge, but is instead synthesizing disparate, incomplete, or conflicting sources of information to produce an integrated picture. Experts who appreciate their role from this perspective are likely to be cooperative.

The fundamental objective of elicitation training is to help the experts accurately express their beliefs as probabilities and pdfs. Training introduces experts to the tasks they must perform. It also identifies their potential biases and provides practice in controlling them. Although practice may not lead to perfect elicitation, evidence shows that practice improves elicitation.¹⁴

VIII. ORGANIZING THE EXPERTS

There are alternative approaches to organizing a group of experts. These approaches vary with respect to the scope of the issues being addressed, the amount and type of interaction among the experts, the amount of redundancy, and the role of the experts in defining objectives. The Sandia/WIPP protocol employs multiple experts and allows for their organization to be based on the dictates of the issue under consideration.

The simplest organization is experts working in isolation from each other. When there are several experts addressing the same issues, redundancy is useful because multiple experts will have alternative viewpoints thereby increasing the potential for describing uncertainty. Alternatively, panels may be organized in which experts work together sharing information and approaches to the issues.

Another strategy for the analysis of complex issues involves multi-disciplinary teams of experts. This approach is relevant when the issue to be addressed is difficult to analyze or decompose into a series of smaller, independent or conditional issues. Multidisciplinary teams

were used for the Futures and Markers Panels.

Once the panel of experts has been organized, their efforts must also be organized. Panels convened to date participated in an initial informational meeting where the issue statement is discussed and the training takes place. The initial meeting is followed by a work period during which the experts consider the issue statement. The actual elicitation of information occurs during the second meeting.

IX. ELICITATION OF INFORMATION

The information that is elicited from the experts may be in several different forms: qualitative recommendations or assessments, pdfs that describe parameter values, and probabilities of particular events or situations.

A. Qualitative Information

The Sandia/WIPP protocol is flexible enough to allow the collection of a broad range of qualitative information. The Futures Panel was asked to develop descriptions of logically possible future societies and possible modes of intrusion associated with those futures. The Markers Panel was asked to develop preliminary marker descriptions that would communicate the location and danger of the waste in the repository and deter inadvertent human intrusion. Experts could also be asked about subjects as diverse as conceptual models of the behavior of natural systems or the appropriateness of modeling assumptions for the performance assessments.

Qualitative information is an important product of expert-judgment elicitation. As the WIPP continues to develop as a compliance-oriented project, and as there is a desire for an external review of various aspects of the performance assessments, qualitative expert judgment may assume a larger role.

B. Quantitative Information

The procedures for the elicitation of probabilities and pdfs are well established and can be found in decision analysis and psychology.^{13,7} Successful elicitation is usually accomplished through the use of specialists, sometimes termed normative analysts, from the fields of probability assessment and decision analysis.¹⁵

One useful design for elicitation is an assessment team working with one expert.⁶ The team members might include a normative analyst who handles the elicitation, a staff analyst who is familiar with the subject area and assists in the communication between the normative analyst and the expert, and a person responsible for documenting the session. For the panels convened to date, elicitation teams included a normative analyst and a staff analyst, but no documentarian.

The elicitation session normally takes place under the control of the normative analyst. The expert is first questioned about the fundamental way he or she has analyzed or decomposed the issue. If the question has been decomposed by the expert, then the decomposition provides the starting point for the discussion. The normative analyst has three goals: to extract the rationales for judgments; to quantify the judgments; and to assist the expert in making the elicited information accurately reflect the expert's knowledge. Reaching these goals requires a good deal of interaction between expert and normative analyst; the former is often challenged to justify his or her beliefs. Each aspect of the elicitation is approached from multiple viewpoints to reveal and resolve inconsistencies.

Care must be taken that the normative analyst and staff analyst share a common understanding of the questions being addressed. In particular, if several assessment teams are working simultaneously, some supervision is needed to ensure the consistency of their efforts. In the study of future societies, some differences among the four teams can be accounted for by the

approaches used by the normative analysts.

Several elicitation techniques are used in the Sandia/WIPP protocol in a single assessment session to facilitate cross and consistency checks. When assessing continuous distributions, for example, direct elicitation of interval probabilities and interval bisection, the process of dividing successive intervals into subintervals of equal probability, can be used together.¹⁶ The analyst guiding the elicitation will ask questions that permit comparisons of probabilities. When inconsistencies are found, the specialist will inform the expert of the incompatibility of the probabilities and assist in modifying the assessments and reconciling the differences.

Complex problems may be decomposed into a number of smaller issues. The principle behind decomposition is that better quality probabilities and pdfs can be obtained when the assessment tasks are easier. There is an increasing amount of empirical evidence supporting this principle.^{17,18} One decomposition tool is the "influence diagram".¹⁹ An influence diagram is a graphical representation showing the interactions of influencing factors and a decision.¹³ Extensive use was made of influence diagrams in the study of future societies for the WIPP Project.

X. RECOMPOSITION

The issue may be decomposed by the Project, by the experts, or through a cooperative effort. During discussions with the experts, the need for expert judgment and its intended use in performance assessment are explained. While the planned use of the results is discussed with the expert panel, the actual recomposition of the elicited information is the responsibility of the Project. This ensures that the recomposed information is compatible with the performance assessment.

The purpose of decomposition is to subdivide a complex problem into components that are easier to

address. During the elicitations, the normative analyst attempts to elicit best estimates of the individual components, without considering what the recomposed result might be. With the Project as the party responsible for the recomposition, there is no opportunity, either intentional or unintentional, for panel members to alter individual component judgments in order to explicitly impact the eventual recomposition.

XI. SUMMARY

Principles from the decision-analysis literature, modified by the experience of convening expert judgment panels, have allowed the WIPP Performance Assessment Department to develop an internal protocol for future expert panels. This protocol supports the production of quality results. The protocol would be appropriate for other repository programs in order to save time and effort in establishing their own protocols.

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