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REPORT OF THE TECHNICAL ADVISORY COMMITTEE ON "UNCERTAINTIES IN THE GROUNDWATER TRAVEL TIME CALCULATIONS AT YUCCA MOUNTAIN, NEVADA" TO SANDIA NATIONAL LABORATORIES

Enclosed is the subject report, which resulted from the committee's meeting in Albuquerque on June 29, 1987.

This is an informal report of a meeting of the Technical Advisory Committee to the task manager, Paul G. Kaplan, and does not necessarily represent the views of Sandia National Laboratories or the Nevada Nuclear Waste Storage Investigations Project on the subject of groundwater travel time calculation or the associated uncertainties.

You will be notified of the next meeting of the committee.

Please address questions on this topic to Jerry S. Szymanski at (702) 295-8941.

Mitchell P. Kunich, Acting Director
Waste Management Project Office

WMPO:JSS-2586

Enclosure:
Report of Technical
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REPORT OF THE TECHNICAL ADVISORY COMMITTEE on "Uncertainties in Groundwater Travel Time Calculations at Yucca Mountain, Nevada"

SAIC/T&MSS

AUG 1 0 1987

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June 29, 1987

Revised July 27, 1987

REPORT OF TECHNICAL ADVISORY COMMITTEE
on "Uncertainties in Groundwater Travel Time Calculations at Yucca Mountain, Nevada", June 29, 1987

1. INTRODUCTION

1.1 TECHNICAL ADVISORY COMMITTEE

A Technical Advisory Committee (TAC) has been established by the Geoscience Analysis Division (Division 6315) of Sandia National Laboratories to advise Sandia on "Uncertainties in Groundwater Travel Time Calculations at Yucca Mountain, Nevada". The members of the TAC are Jacob Bear, R. Allan Freeze (Chairman), Milton E. Harr, R. William Nelson, and Benjamin Ross. Appendix A provides addresses for each.

This report summarizes the meeting of the TAC held at the Ramada Classic Inn in Albuquerque, New Mexico on June 15-16, 1987. All five members of the TAC were present, together with twelve representatives of Sandia and their contractors, and six invited observers from other agencies. Appendix B provides a list of the participants.

1.2 OBJECTIVES OF THE MEETING

The general charge to the TAC is threefold: (1) to review the models and modeling procedures currently being used to estimate groundwater travel time (GWTT) at Yucca Mountain; (2) to review the various sources of uncertainty involved in these estimates; and (3) to recommend future work aimed at reducing these uncertainties. To this end, Sandia requested that members of the TAC fill in a form prior to the Albuquerque meeting that identified the sources of uncertainty, their relative influence on groundwater travel time, and the potential experimental approaches and numerical approaches for reducing uncertainty. Appendix C provides a sample form. The completed forms and the letter reports that accompanied them became the source materials for the TAC meeting. It is recognized by all that consideration of uncertainty will lead to a probability density function (PDF) or cumulative density function (CDF) for GWTT rather than a deterministic value.

With this background, the specific objectives of the Albuquerque meeting can be placed in context. Appendix D presents the set of Technical Meeting Objectives and Procedural Meeting Objectives provided by Sandia. They can be summarized as follows:

1. Prepare a comprehensive list of uncertainties by class, and include a working definition of each class.

1. INTRODUCTION, cont'd.

1.2 OBJECTIVES OF THE MEETING, cont'd.

2. Estimate the likely relative influence of each uncertainty on the GWTT CDF, noting areas of clear consensus or clear disagreement among the TAC members.
3. Prepare an informal written report.
4. Suggest the future mode of operation of the TAC.

In the remaining subsections of Section 1, we discuss several background issues that will lay the foundation for the later sections. In Section 2, we address objectives 1 and 2 in the form of a comprehensive table of uncertainties. In Section 3, we try to summarize the findings of Section 2 by providing a list of major issues identified. In Section 4 we address Objective 4 by providing a set of recommendations for the future role of the TAC. This report in itself satisfies Objective 3.

1.3 MODELING & MODELING PROCEDURES

In order to make decisions with respect to site characteristics, environmental impact and site licencing, Sandia management requires information about the natural behaviour of the current system and the future behaviour of the managed system. The managed system includes the repository and the subsurface domain between the disturbed zone, and the accessible environment. At this stage, our interest focusses mainly on the natural system, and in particular, on the pre-emplacement groundwater travel time.

Models of the system and its behaviour are the tools for providing the information needed for decision-making. In addition to their direct role in providing an estimate of the likelihood of meeting regulatory performance criteria, they help the planner to understand the system, its internal structure, and its behaviour under various stresses. A sensitivity analysis performed on models will indicate the relative significance of various processes and mechanisms, and will guide management in the acquisition of additional field data and in the design of the engineered barrier system at the repository and the monitoring system that will be required to confirm the predicted system performance.

For the purposes of this report, we define a model as a simplified version of the real system, one that simulates those excitation-response features of the real system that will provide the information required by the decision-maker. The construction of models is based on an understanding of the system, and because of its complexity, a simplification of the real system. The simplification is usually introduced in the form of a set of assumptions that together constitute the conceptual model of the real system. Establishing the conceptual model is the first step in the modeling procedure.

1. INTRODUCTION, cont'd.

1.3 MODELING & MODELING PROCEDURES, cont'd.

The second step is the construction of a mathematical model that expresses the conceptual model in mathematical terms. In the traditional methodology, wherein the system is modelled as a continuum (or a number of continua), the mathematical model usually takes the form of a boundary-value or initial-value problem based on one or more partial differential equations.

In the process of simplifying the real system to the model form, a number of coefficients are introduced. These express macroscopic manifestations of the microscopic structure of the system. While these are usually defined so as to have macroscopic physical significance, we emphasize that particular coefficients are always associated with a specific form of the model and are not general features of the system.

For a continuum model, a standard structure includes:
(1) specification of the domain boundary; (2) specification of the balance equations of the transported extensive quantities; (3) specification of the relevant constitutive relations of the fluid and solid materials present in the system; (4) specification of expressions for the various fluxes, in terms of the state variables of the system; and (5) specification of initial and boundary conditions.

In general, the transported quantities could include water, vapor, heat, or contaminants. For the travel time problem, and within the framework of the present study, they will refer only to the travel of water, and possibly vapor.

The balance equations are written in terms of a set of state variables. The constitutive relations include a set of coefficients and the flux expressions. When the model is used in a forward (or direct) sense, (i.e., to predict the future values of the state variables that describe the state of the system) the values of the coefficients that appear in the model must be provided as input. These coefficients are obtained from (natural or artificial) field experiments by the process referred to as solving the inverse problem. In such a process, field data such as drawdowns or concentrations are measured as functions of space and time, and inserted in the model. The model is then solved for the unknown values of the coefficients. The term model calibration is often used for the trial and error procedure of determining the values of the coefficients that give the best fit between predicted and observed data. Model calibration is an on-going process; as more data becomes available, the model is repeatedly calibrated to provide updated values of its coefficients. By comparing predicted and observed data, we actually achieve two goals. One is model validation (i.e., ensuring that the model does indeed describe observed phenomena), and the second is the determination of model coefficients.

1. INTRODUCTION, cont'd.

1.4 UNCERTAINTY

If we look at the modeling procedure and the standard structure for a continuum model as presented above, it is clear that there is uncertainty in all five aspects. There is uncertainty in the location of the domain boundaries. There is uncertainty in the coefficients appearing in the constitutive relations. There is uncertainty in the flux expressions and in the coefficients that appear in them. There is uncertainty in the types of initial and boundary conditions, and in the values associated with their specification. There is even uncertainty in the nature of the conceptual model that will be used for the prediction of groundwater travel time. For example, should balance equations be written for a single continuum, or for a double-porosity type of model. Altogether we have: (1) uncertainty in the model, and (2) uncertainty in the various coefficients and parameters that appear in the model. One of the primary goals of the NNWSI program is to reduce these uncertainties.

Uncertainty can be reduced by experimental approaches and by numerical approaches, and these two broad classes were recognized on the forms provided to TAC members by Sandia. Experimental approaches include: (1) field determination of coefficients for direct input to the model; (2) field measurements of state variables for the purpose of model validation, and for using inverse methods to estimate coefficient values; (3) field and laboratory experiments to aid in developing and confirming conceptual models; and (4) field observation of indirect evidence that can aid in developing and confirming conceptual models. Numerical approaches consist primarily of sensitivity analyses carried out with numerical solution techniques on mathematical models of specific conceptual models.

Perhaps the most difficult issues are associated with uncertainties in the conceptual model. Because of the simplifications involved, there is no unique model for the problem under consideration. For a while, it may be necessary to develop a number of models (all of them feasible) in parallel, trying to draw conclusions from all of them with respect to groundwater travel time.

There are a variety of methods available for quantifying the prediction uncertainties that arise from uncertainties in input values for specific conceptual models. Among them are Monte Carlo analysis, spectral methods based on perturbation analysis, and first-order, second-moment analysis. We do not assess the relative merits of these approaches in this report, but such an assessment would provide a very suitable topic for a later meeting of this committee.

1. INTRODUCTION, cont'd.

1.4 UNCERTAINTY, cont'd.

In this regard, we note that the discussion thus far (and the format of the forms provided by Sandia, and the objectives set out for the meeting) presupposes the general nature of the model that will be used to analyse travel times. It is based on the traditional approach wherein attempts are made to understand the physics of flow, and the physics forms the basis for a mathematical model. Uncertainty is introduced mainly through stochastic descriptions of the coefficients and boundary conditions. We believe that this approach is the most likely one to be followed at Yucca Mountain, but we do not dismiss the potential for non-traditional stochastic approaches. In Appendix E, Dr. Harr outlines the basis for some of these non-traditional approaches.

1.5 DEFINITION OF GROUNDWATER TRAVEL TIME

Under NRC regulations, pre-emplacement groundwater travel time is one of the measures that is used to determine acceptability of a site. Pre-emplacement conditions are interpreted as the natural conditions existing at the site before exploration and construction begins. With respect to the Yucca Mountain site, the definition of GWTT has some ambiguity. It is not our intention to try and resolve these ambiguities but we do wish to draw attention to them. The three ambiguities we will address are those associated with: (1) fracture-matrix exchange; (2) spatially-distributed flow paths; and (3) the degree of certainty required.

First, it is not clear how the concept of water travel time is to be interpreted if, as seems possible at Yucca Mountain, there is incomplete mixing between water flowing through fractures and relatively immobile water in the pore spaces of the tuff. In such a case, molecular diffusion would be a principal means by which water and solutes exchange between fractures and pores. The speed of migration of a contaminant would depend on its diffusion constant, so that high-molecular-weight contaminants could conceivably escape more rapidly than would a "tagged" molecule of water. In this report, we have assumed that the final definition of travel time reflects diffusional exchange in some way (rather than equating groundwater velocity to the advective velocity of water in fractures), but we have not tried to develop a specific defintion.

On the second issue, it appears that the regulation implicitly assumes that one or more distinct paths of groundwater flow can be identified and that each of them has associated with it a unique travel time. At Yucca Mountain the path segment from the repository to the water table has a length of a few hundred meters and a cross-section of several square kilometers, across

1.5 DEFINITION OF GROUNDWATER TRAVEL TIME, cont'd.

which there is a large variation in stratigraphy. The size of the proposed repository and the complexity of the site geology will lead to distributed sources, multiple pathways, and uncertainty as to which pathway is the most critical. We cannot accept a single-source, single-pathway type of analysis; the uncertainty analysis included in this report assumes a two-dimensional or three-dimensional stochastic modeling approach.

Lastly, there is ambiguity as to the degree of certainty required with respect to satisfying the 1000-year pre-emplacement travel-time criteria. A GWTT CDF will always show some finite (although hopefully very small) probability of failing to meet the criteria. What is required is some regulatory recognition of the concept of acceptable risk with respect to GWTT.

1.6 POST-EMPLACEMENT CONDITIONS

The objectives of the TAC meeting in Albuquerque dealt solely with pre-emplacement groundwater travel time. The committee recognizes the source of this limited objective in the 1000-year pre-emplacement - GWTT regulatory criteria. However, we wish to place on record our concern that consideration of this issue outside the context of a more complete analysis of pre- and post-emplacement flow and transport issues might be misleading with respect to the conclusions drawn. Concepts and parameters whose uncertainties have only limited impact on GWTT might have considerable impact on transport mechanisms and radioisotope flux rates, and vice-versa. This issue is raised again in the final sections of this report where we consider the future role of the TAC.

2. EVALUATIONS OF UNCERTAINTY

2.1 CLASSIFICATION OF UNCERTAINTY

With the introductory concepts and caveats of Section 1 in hand, we now suggest a threefold classification of uncertainty for the GWTT problem. The three classes are: (1) Model Uncertainty; (2) Parameter Uncertainty; and (3) Calibration Uncertainty. They are defined as follows:

Model Uncertainty -

Uncertainty in the concepts underlying the suite of equations, boundary conditions and initial conditions used to make predictions; and uncertainty in the geometry of the region in which the equations apply, and in the broad geological zonations within it.

2. EVALUATIONS OF UNCERTAINTY, cont'd.

2.1 CLASSIFICATION OF UNCERTAINTY, cont'd.

Parameter Uncertainty -

Uncertainty in the numerical values of the coefficients that appear in the equations, in the initial conditions, and in the boundary conditions.

Calibration Uncertainty -

Uncertainty in the state variables, the measurement of which feeds back into both inverse estimates of the coefficients and the confirmation of the model structure; and uncertainty in indirect measures of model variables and parameters arising from such techniques as geochemical interpretation and age dating.

Table 1 indicates how we anticipate that research experiments, field measurements, and numerical simulations, will lead to improved confidence in the selected model and reduced uncertainty in coefficient values.

Table 2 provides an expanded classification system in which the three main classes of uncertainty are each divided into two subclasses, and some of these are divided yet again. In the following section, the threefold identification system (e.g., A.I.1) of Table 2 is used to list our detailed identification of sources of uncertainty in estimating GWTT.

Two comments of clarification with respect to Table 2 are in order. First, if the conceptual model involves only steady-state rather than transient flow, then uncertainties due to the type of initial conditions (A.I.3) or their values (B.IV.) will not arise. Second, in transient analyses, where initial conditions are pertinent, the uncertainties in the state variables arise in two contexts: (1) as they influence the values of the initial conditions in B.IV.; and (2) as they influence the inverse calculation of coefficients in C.V.

2.2 ESTIMATE OF RELATIVE INFLUENCE OF UNCERTAINTIES ON GWTT CDF

Table 3 provides a preliminary consensus of TAC members as to the relative impact of specific sources of uncertainty on the GWTT CDF. The sources of uncertainty are grouped under headings based on the classification presented in Table 2. In Table 3, a qualitative measure of relative impact has been selected for each source of uncertainty from a fourfold classification scheme. Relative impact is judged to be: (1) High; (2) Medium; (3) Low; or (4) Insignificant.

2. EVALUATIONS OF UNCERTAINTY, cont'd.

2.2 ESTIMATE OF RELATIVE INFLUENCE OF UNCERTAINTIES ON GWTT CDF, cont'd.

Sandia requested that we provide an estimate of the relative impact of uncertainty on both the mean and the variance of the GWTT CDF. We have not been able to make such a separation. Our relative impacts should be taken as applying to both moments. If such an analysis proves possible in the future, we would recommend that the impacts be specified with respect to the coefficient of variation rather than the variance.

The measures of relative impact given on Table 3 are qualitative. For three of the subclasses identified on Table 2 (I, II and VI), uncertainty analysis is likely to remain qualitative. The other three subclasses on Table 2 (III, IV and V) will lend themselves to quantitative uncertainty analysis in due course.

We wish to emphasize that there is not a one-to-one correspondence between large uncertainties and high relative impact. Some physical properties may be quite uncertain but are judged to have little impact. Table 3 presents estimates of relative impacts on GWTT CDF, not estimates of the size of source uncertainties.

Neither is there a one-to-one correspondence between high relative impact on GWTT CDF and high priority in the development of Sandia programs for Yucca Mountain. In some cases, uncertainties with high relative impact may be difficult to reduce and efforts would be better placed trying to reduce overall uncertainties by attacking a more tractable source. Because of this lack of one-to-one correspondence, we have marked an asterisk on Table 3 beside those sources of uncertainty where we judge efforts would be best placed in trying to reduce overall uncertainties. These sources are further highlighted in Section 3.

In the same column as the asterisks on Table 3, some sources of Low Relative Impact are marked with a del. This symbol identifies sources of uncertainty that have little impact on GWTT CDF but could have significant impacts on radioisotope transport times and flux rates.

In perusing Table 3, one must be constantly reminded that it does not document which mechanism or parameters have a large relative impact on GWTT. Rather, it documents which mechanisms or parameters have uncertainties associated with them that have a large relative impact on the GWTT CDF.

Some comments are in order with respect to Section B.III.1 of Table 3 which deals with uncertainties in the media coefficients. Note that we have not placed asterisks beside (a) and (b) - the relative saturation and relative permeability curves.

2. EVALUATIONS OF UNCERTAINTY, cont'd.

2.2 ESTIMATE OF RELATIVE INFLUENCE OF UNCERTAINTIES ON GWTT CDF, cont'd.

We do not recommend heavy Sandia effort in the direct determination of these parameters. A more likely source of information on these medium properties lies in inverse numerical sensitivity modeling. What effort is placed on direct measurement should emphasize matrix properties and water flow. In principle, the relative saturation and relative permeability curves (and the saturated permeability and porosity) should be determined for all formations (or more accurately, for all rock types). However, we recommend particular emphasis on two materials: (1) Calico Hills non-welded tuffs, which may offer the best radioisotope containment, and (2) fault-zone materials, which may offer the fastest transit routes.

Benjamin Ross holds somewhat different views on the relative impact of uncertainty in medium parameters. His dissenting opinion can be found in Appendix F.

For Section C of Table 3, note that the state variables in C.V are of primary use in reducing uncertainties in media coefficient values; the indirect measures in C.VI are of primary use in improving confidence in the conceptual model.

Note in Section C.V of Table 3, an example of a variable whose uncertainty is judged to have a low influence on the GWTT CDF, yet an asterisk identifies it as worth Sandia attention. Water table position is relatively easy to measure, and inverse interpretations can aid in unravelling media coefficient values.

3. SUMMARY OF MAJOR ISSUES

Table 4 provides a summary of the TAC consensus of the uncertainties of greatest significance. It is in the reduction of these uncertainties (through research experiments, numerical experiments, and field measurements) that we judge priority should be placed in the Sandia program. The items on Table 4 summarize the asterisked items from Table 3.

4. RECOMMENDATIONS ON THE FUTURE ROLE OF THE TECHNICAL ADVISORY COMMITTEE

a. The TAC members feel that their value to Sandia would be increased if the scope of the committee assignment were increased from review of the groundwater travel time issue alone to include a broader suite of flow and transport issues possibly including the impact of these issues on repository design and performance. We recognize that a broadened mandate would lead to committee interaction across Sandia divisional boundaries, but we hope that this is not an insurmountable problem. We understand that there is interest in a broadened mandate from Sandia personnel involved in various aspects of the NNWSI project.

b. The TAC members feel that the current membership provides sufficient coverage of most of the disciplines needed to review the travel time issues or a broadened flow-transport performance mandate. Specifically, we find ourselves sufficiently well-versed in transport theory, numerical methods, stochastic approaches, saturated and unsaturated flow theory, hydrogeological interpretation, and engineering design. The area that we do not cover adequately is hydro-geochemistry. We recommend the addition of a member versed in isotopic and elemental water geochemistry, age dating, and chemical aspects of radioisotope transport. We feel that a committee of five (or at most six) members is optimal.

c. We do not favor the issuing of formal reports of our activities. We favor the type of informal report we are using to summarize the Albuquerque meeting as the modus operandi.

d. The presence of outside observers at the Albuquerque meeting was a positive step that should be encouraged for future meetings. The TAC earlier recognized the need for greater integration of the programs of the four contributing NNWSI agencies, and interactions at joint meetings serves this need. In addition, interaction between NNWSI personnel and regulatory personnel cannot help but lead to increased awareness on both sides.

e. We recommend that the TAC meet with Sandia personnel 3-4 times per year for 2-3 days each time.

f. The TAC would very much appreciate a one- or two-day briefing session by Sandia staff and other NNWSI contractors. We would like it to include an explanation of the Sandia organizational structure, and representative technical presentations from across this structure.

g. Potential topics for future meetings include: (1) uncertainty analysis for radioisotope transport under post-emplacement conditions; (2) discussions of various methods of uncertainty analysis; (3) review of field measurement and experiment programs (USGS, LANL) in terms of Sandia design and performance assessment needs; and (4) review of numerical sensitivity approaches to uncertainty reduction.

Table 1 - PURPOSE AND METHODOLOGY OF UNCERTAINTY ANALYSIS

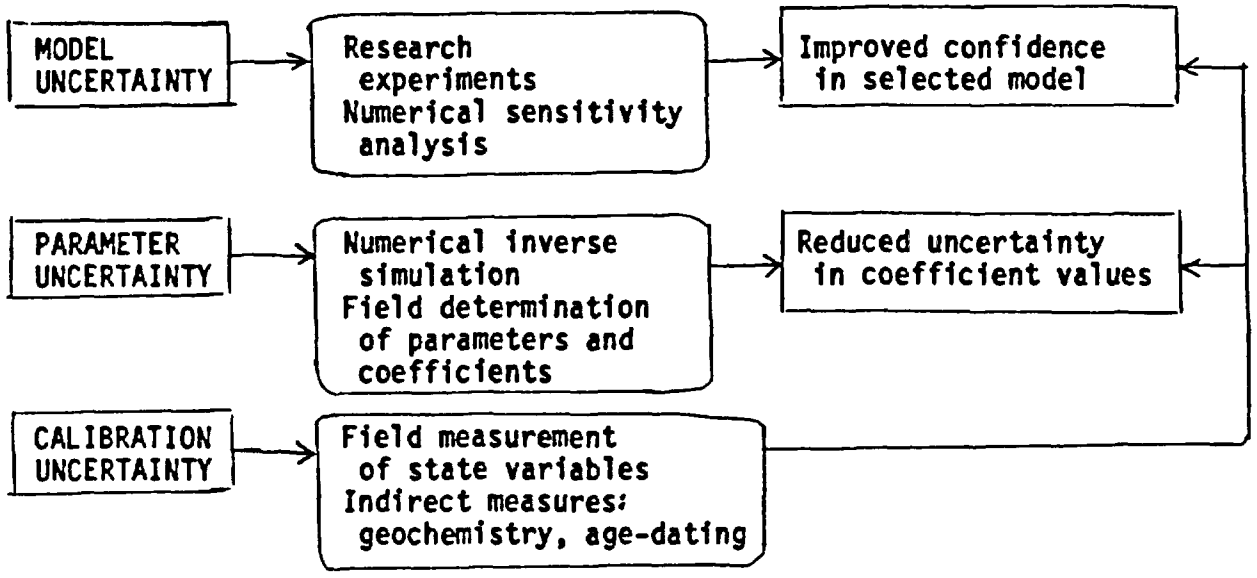

Table 2 - CLASSIFICATION OF UNCERTAINTIES

A. Model Uncertainty

I. Equations and Type of Boundary and Initial Conditions

1. Fluid-related considerations
2. Media-related considerations
3. Type of boundary and initial conditions

II. Domain Geometry and Geological Framework

1. Domain geometry
2. Geological framework

B. Parameter Uncertainty

III. Coefficients

1. Media properties
2. Fluid properties

IV. Values of Boundary and Initial Conditions

C. Calibration Uncertainty

V. State Variables

VI. Indirect Measures

Table 3 - EVALUATION OF UNCERTAINTIES

A.I.1 Model Uncertainty - Fluid-related Considerations

UNCERTAINTY	REL. IMPACT	
a. One phase flow or two phase flow	High	*
b. Isothermal system or non-isothermal system	High	*
c. For non-isothermal system: vapor flow or no vapor flow	Medium	*
d. For non-isothermal flow with no vapor flow:		
i. Fluid density variations	Low	∇
ii. Viscosity variations	Low	∇
iii. Surface-tension variations	Low	∇
e. Fluid compressibility effects	Insig.	
f. Coupled phenomena	Insig.	∇

A.I.2 Model Uncertainty - Media-related Considerations

UNCERTAINTY	REL. IMPACT	
a. Fracture-flow/matrix-flow interactions	High	*
b. Spatial variability in fracture/ matrix properties:		
i. Fractures	High	*
ii. Matrix	High	*
c. Dead-end pore effects on unsaturated fracture/ matrix properties	High	*
d. Media compressibility effects	Insig.	

* Major issue.
∇ Could have significant impact on radioisotope transport times and flux rates.

Table 3 - EVALUATION OF UNCERTAINTIES, cont'd.

A.I.3 Model Uncertainty - Type of Boundary and Initial Conditions

	UNCERTAINTY	REL. IMPACT	
a.	Upper boundary condition: spatial uniformity of infiltration	High	*
b.	Upper boundary condition: depth of surface zone of transient response to infiltration events	Low	
c.	Upper boundary condition, past: steady state infiltration or Pleistocene decay	High	*
d.	Upper boundary condition, future: steady state infiltration or long-term episodic variations	High	
e.	Lateral boundary conditions	Insig.	
f.	Bottom boundary conditions	Insig.	
g.	Initial condition	Low	

* Major issue.

Table 3 - EVALUATION OF UNCERTAINTIES, cont'd.

A.II.1 Model Uncertainty - Domain Geometry

UNCERTAINTY	REL. IMPACT
a. Dimension of analysis: 1D, 2D, or 3D	High
b. Lateral extent of modeled region in 2D or 3D	Med.

A.II.2 Model Uncertainty - Geological Framework

UNCERTAINTY	REL. IMPACT	
a. Distribution of geological formations	Low	
b. Distribution of rock types within geological formations:		
i. welded/non-welded layers	High	
ii. vitric/non-vitric layers	Low	
iii. zeolitic/non-zeolitic layers	Med.	∇
iv. lithophysal cavity concentration	Med.	
c. Nature of stratigraphic contacts between rock types:		
i. capillary barriers	High	*
ii. perched zones/lateral flow	High	*
d. Number, location, thickness, continuity and hydraulic significance of fault zones	High	*

* Major issue.
∇ Could have significant impact on radioisotope transport times and flux rates.

Table 3 - EVALUATION OF UNCERTAINTIES, cont'd.

B.III.1 Parameter Uncertainty - Coefficients - Media

UNCERTAINTY	REL. IMPACT	
a. Relative, saturation curves:		
i. water, matrix	High	
ii. air, matrix	Low	
iii. water, fractures	Med.	
iv. air, fractures	Low	
b. Relative permeability curves:		
i. water, matrix	High	
ii. air, matrix	Low	
iii. water, fractures	Med.	
iv. air, fractures	Low	
c. Saturated permeability:		
i. matrix	High	*
ii. fractures	High	*
d. Porosity:		
i. matrix	High	*
ii. fractures	High	*

B.III.2 Parameter Uncertainty - Coefficients - Fluids

UNCERTAINTY	REL. IMPACT
a. Fluid density:	
i. air	Insig.
ii. water	Insig.
b. Fluid viscosity:	
i. air	Insig.
ii. water	Insig.
c. Surface tension:	
i. air	Insig.
ii. water	Insig.

* Major issue.

Table 3 - EVALUATION OF UNCERTAINTIES, cont'd.

B.IV Parameter Uncertainty - Boundary and Initial Conditions

UNCERTAINTY	REL. IMPACT	
a. Upper boundary conditions: infiltration rates	High	*
b. Lateral boundary condition:		
i. water heads, pressures, or moisture contents	Low	
ii. air pressures, temperatures	Low	
c. Initial conditions:		
i. water heads, pressures, or moisture contents	Med.	
ii. air pressures, temperatures	Low	

C.V Calibration Uncertainty - State Variables

UNCERTAINTY	REL. IMPACT	
a. Water pressures or heads	High	
b. Moisture contents	Med.	
c. Air fluxes	Low	
d. Relative humidity	Low	
e. Water table position	Low	*
f. Temperatures	Low	

* Major issue.

Table 3 - EVALUATION OF UNCERTAINTIES, cont'd.

C.VI Calibration Uncertainty - Indirect Measures

	UNCERTAINTY	REL. IMPACT	
a.	Radioisotope concentrations in water and gas	High	
b.	Stable isotope anomolies for water and gas	Low	
c.	Chemistry of water in unsaturated zone	Low	
d.	Silicate weathering, including zeolitization	Med.	∇
e.	Petrology of fracture coatings	Low	∇
f.	Isotopic and elemental geochemistry of water in saturated zone for age dating and recharge location	High	*
g.	Amount and location of moisture inflow to exploratory shaft working (Humidity of ventilation exhaust, drips, mineral efflorescence on walls, etc.)	High	
h.	Migration of tagged drilling fluids	Med.	
i.	Air flow in boreholes	Med.	

* Major issue.
∇ Could have significant impact on radioisotope transport times and flux rates.

Table 4 UNCERTAINTIES OF GREATEST SIGNIFICANCE FOR SETTING PRIORITIES IN SANDIA NNWSI PROGRAM

A. Model Uncertainties

1. Fracture-flow/matrix flow interactions; dead-end-pore effects on fracture/matrix flows; spatial variability in fracture/matrix properties.

2. Nature of stratigraphic contacts between rock types; occurrence of capillary barriers; occurrence of perched zones/lateral flow.

3. Number, location, thickness, continuity, and hydraulic significance of fault zones.

4. Upper boundary condition: spatial and temporal uniformity of infiltration.

5. Two-phase flow effects: importance of vapor flow, non-isothermal effects.

B. Parameter Uncertainties

1. Upper boundary condition: infiltration rates.

2. Saturated permeability and porosity of matrix and fractures, especially for Calico Hills and fault zone materials.

C. Calibration Uncertainties

1. Water-table position.

2. Isotopic and elemental water geochemistry for age dating and recharge location interpretation.

APPENDIX A

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APPENDIX B

PARTICIPANTS

Sandia National Laboratories, Division 6315
Geoscience Analysis Division

Second Meeting
Technical Advisory Committee
"Uncertainties in Groundwater Travel Time Calculations
at Yucca Mountain, Nevada"

June 15th & 16th, 1987
Ramada Classic, Albuquerque, New Mexico

Sandia Personnel, Contractors, & Consultants

Jacob Bear
R. Allen Freeze
Milton H. Harr
William Nelson
Ben Ross
Joe Wang
Polly Hopkins
Ralph Peters
Brian Rutherford
Dave McTigue
Roger Eaton
Bob Prindle
Paul Kaplan
George Barr
Scott Sinnock
Floyd Spencer
Lee Orear

Invited Observers

Richard Codell - NRC
Dwight Hoxie - USGS
Gail Cederberg - Los Alamos
Kay Birdsell - Los Alamos
Marty Mifflin - Nevada
Mike Campana - DRI

APPENDIX C.

	RELATIVE INFLUENCE				EXPERIMENTAL APPROACHES				NUMERICAL APPROACHES				
0 SOURCE OF UNCERTAINTY	1 Likely Relative Influence on Transport CDF		2 Likely Relative Influence on GWTT CDF		3 Experimental Approach to Quantify Uncertainty	4 Status of Experimental Capabilities	5 Indirect Test Methods for Inferring Parameters	6 a Priority of 100 Dollars	7 Numerical Approach to Incorporate Uncertainty	8 Status of Numerical Capabilities	9 Available Codes	10 a Priority of 100 Dollars	11 Comments
	mean	var	mean	var									
Model uncertainty													
Parameter uncertainty													

APPENDIX D

Technical Meeting Objectives

1. Are the following objectives for the current meeting reasonable?
   a. If the objectives are totally unreasonable then contact me immediately. If not, submit any changes or reccomendations to me after lunch.

2. Prepare a comprehensive list of uncertainties by class.
   a. Two current classes exist.
      i.) Model Uncertainties
      ii.) Parameter Uncertainties
   b. Are these two classes all inclusive?
   c. If the answer to the above question is yes, then prepare a working definition of each class.
   d. If the answer is no, identify additional classes of uncertainties and prepare definitions.

3. Estimate the likely relative influence on the GWTT CDF of each uncertainty.
   a. Include effect on both the mean and variance.
      i.) This particular exercise will help Sandia prioritize current studies.

4. Identify areas of clear consensus and clear disagreement.

5. Choose a main author and prepare an informal written report of all objectives addressed during the meeting. Dissenting opinions should be authored by the dissentor and presented as an appendix to the report. By the same token, those who feel that certain points need amplification or clarification should append those comments to the report.

Procedural Meeting Objectives

1. Is the current panel well-rounded or are additional skills needed?
   a. What skills specifically?
      i.) Who, by name, would you suggest?

2. Would a formal report on the technical objectives help to clarify current thinking and provide direction for future tasks?

3. Should we meet again? If so, when? For how long?

4. Do objectives for the next meeting suggest themselves?
   a. If so, what are they?

5. Would a day or two of meetings and presentations by Sandia staff and contractors addressing issues relevant to uncertainties in travel time calculations be profitable?
   a. Should this time be included with our next meeting?

6. Did the presence of outside observers benefit or detract from the meeting?

APPENDIX E

A "DISCRETE-MODEL" APPROACH

Milton Harr

The modeling of the flow media referred to in the body of this report is understood to follow customary continua formulations. That is, energy balances are invoked at "macroscopic statistical equivalent" points to produce (governing) differential equations. Degrees of isotropy are introduced to account for directional dependence (at a point) and homogeneity is pleaded to extend the developed G.D.E.s from the ficticious "point" to body-wise attributes. Boundary and initial conditions and parametric descriptions scale the dependent variables.

In a continuum approach there is no "a priori" knowledge of the movement of water from one point to another: it is accommodated by the assumption of homogeneity. An alternative modeling is proposed herein that takes cognizance of a predicted path of flow. Conceptually, a cross section (for a 2-dimensional solution) is prepared that demonstrates the anticipated stratigraphy and fracturing in a vertical plane through the site. The cross section is then divided into a (large) number of horizontal layers. A point on the upper surface of the medium is selected as a starting point. As the particle enters each of the layers it reacts mechanistically (as per continuum model) to the characteristics of the flow medium and fracturing previously specified for the "thin layer". The process continues from layer to layer until the particle reaches either an equilibrium state or a boundary.

Once the path for the single particle has been computed, by applying the "2xn" point-estimate-method, the expected value and standard deviation of the travel time can be obtained for the initial point. The process would then be repeated for a number of points on the "upper" surface. The successful pursuit of this model would produce the distribution of expected values and of the standard deviation of the travel times.

From a conceptional point of view the "discrete model" permits one to account for the heterogeneous nature of the site and for the evident fracturing. It should be emphasized that it is not the intent of this model to replace conventional continuum modeling: it is offered as a parallel methodology.

APPENDIX F

A DISSENTING OPINION ON THE IMPACT OF UNCERTAINTY IN MEDIA COEFFICIENTS

Benjamin Ross

The evaluation presented by the committee for the relative impact of uncertainty in medium parameters (Section B.III.1 on page 16) is based implicitly on the idea that water velocity will be calculated by solving Richards' Equation. There is an alternative approach which is valid as long as flow is confined to the rock matrix in a sizable portion of the section. To calculate the flow velocity in regions where there is only matrix flow, one simply divides the average infiltration rate by the ambient moisture content. Fracture flow is so rapid that one can ignore the contribution to travel time of the zones where it occurs. With this model, the only medium parameters that have a high degree of influence on the travel time are the matrix saturated permeability (which determines whether fracture flow occurs for a given infiltration rate) and the ambient moisture content. (Infiltration rate is also important, but it is a boundary condition, listed under a different heading.)

This simple algebraic model involves considerable simplification of the three-dimensional variability of the system, and so it is not clear whether one will actually calculate travel times with it or with Richards' Equation. Even if Richards' Equation is used, however, it seems to me that the algebraic model captures the essential physics of the situation. Whatever calculations are made, pre-emplacement travel time should turn out to be fairly insensitive to all medium parameters other than ambient moisture content and matrix saturated permeability. (To be sure, many of the other medium parameters will be important to the post-emplacement transient response of the system.)

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