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RESPONSE TO NRC'S WRITTEN COMMENTS

Techniques for Determining the Probabilities of Events and Processes  
Affecting Geologic Repositories:  
Volume 1--Literature Review

On September 29 and 30, 1986, Bob Cranwell, Regina Hunter, and Bob Guzowski of Sandia met with Sandra Wastler in Silver Spring to discuss Sandia's responses to NRC's comments on this report. Verbal agreement was reached about the changes to the report. It was agreed at that meeting that no written responses would be required. We deeply regret any impression on the part of NRC staff that comments were ignored, and we are happy to provide written responses at this time. Many of the changes in response to comments are not to be found in the chapter specifically commented on by an individual reviewer, but rather have been incorporated into the Introduction, Executive Summary, or Foreword, where several pages worth of new material has been added. Although not all comments were incorporated (for the reasons given below), every comment was considered.

The NRC comment package comprised 210 individual written comments. Our responses can be summarized as follows:

- o 90 comments, or 43%, have resulted in changes to the text. Of these
  - 33 comments, or 16%, requested a change that was outside the purpose or scope of work for the task, report, or chapter. We indicate below which comments were outside the purpose or beyond the scope of work. We have added 10 pages of material to the Foreword, Executive Summary, and Introduction to clarify the scope, purposes, and goals of this report.
  - 57 comments, or 27%, call for changes that have been incorporated in some form into the text. These include misreadings of an unclear text, which we have clarified.
- o 42 comments, or 20%, discuss the material without calling for any change to the text (or discuss something else entirely, e.g., work by another contractor or a paper by another author). We indicate below which comments these were. The text has been left unchanged.
- o 78 comments, or 37%, call for changes that have been considered but rejected. These include simple misreadings of an already clear text, which we have explained here.

GENERAL

Several reviewers had incorrect ideas about the purpose and scope of this report, possibly because they did not have access to the Introduction, or possibly because the purpose and scope were not well explained. Although we respond individually to these comments below, general remarks are in order here.

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Before and during licensing, DOE will prepare a performance assessment and NRC will evaluate it. The primary purpose of the probability report is to put NRC into a position to evaluate the probabilities DOE assigns to the events, processes, and scenarios considered in the performance assessment. As stated in the Introduction, p. 1-3, this report was intended as a literature review documenting existing probabilistic techniques in selected fields related to the long-term performance of a repository. The SOW (dated 84/10/11) and the 189 contain the passage "Each expert shall be asked to identify quantitative techniques for assigning probabilities of occurrence ... If more than one defensible technique exists ..., all should be considered. ... The contractor shall submit a final report which includes the techniques identified, the experts' evaluations of the techniques, ..., and recommendation for improvement in the techniques or alternative for determining probability of occurrence" (emphasis added). The 189 goes on to state, in 4. Description of Any Follow-On Efforts, "The effort to develop new techniques for determining the probabilities of events and processes will probably not be initiated until FY 86. Only the portion of the Task devoted to identifying existing techniques is funded for FY 85" (emphasis in the original). The Program Plan also refers repeatedly to the "literature review," and has two subtasks called "Review Literature and Document Existing Technique" and "Prepare Final Report Documenting Existing Techniques." Several reviewers have asked that material be added that is outside the scope of work for this report, but this material has not been added. Each of these requests is addressed below under "Specific." In addition, material has been added to the Introduction, Executive Summary, and Foreword clarifying the scope of the report.

Some reviewers suggest that the report "endorses" one technique or another. The final draft contains a disclaimer on the first page of every chapter stating that discussion of techniques does not constitute endorsement by the NRC or SNLA. It is impossible to predict the particular methods of probability assignment that DOE will choose to use; NRC must have some means of assessing whatever DOE submits. Therefore, this report discusses and evaluates all methods the experts found, or at least as many as possible given the constraints of time and money. Discussion and evaluation of the methods should not be construed as endorsement. There is a brief section at the end of each chapter that was called "Recommendations" in the draft. The title of this section has been changed to "A Currently Feasible Approach" to avoid the suggestion of endorsing one method or another. This section is intended to present a means of assigning probabilities that could be used now, with no further developmental work, so that NRC can judge whether DOE has used the best available method.

Other reviewers suggested that the report is flawed because one chapter or another does not directly address waste-management issues. We are preparing this literature review precisely because probabilistic techniques for addressing waste-management issues are as yet largely not agreed upon; in preparing their chapters, the experts were obviously constrained by the existing literature. We have renamed the report to emphasize that it is a literature review only.

Finally, several reviewers have commented on those sections of the report that treat uncertainty, saying variously that more or less treatment would be appropriate. It has been clear from the beginning of this effort that the

probability of rare events will of necessity be treated somewhat differently from probability of changes in ongoing processes, with the latter more likely to be treated using parameter uncertainty. Hence, the title includes the phrase "events and processes." The treatment of uncertainty will be addressed in substantial detail under a separate task of A-1165, but in this report, uncertainty is addressed in a preliminary way in some chapters, ~~particularly those that deal with processes like ground water flow and thermomechanical effects.~~ In addition, a section has been added to the Introduction explaining that the events and processes were chosen for their functional similarity, not because they are treated similarly.

### SPECIFIC

Many responses below state that a request is beyond the scope of the report. Material added to the Foreword, Executive Summary, and Introduction and the change in title are intended to address these requests; no changes have been made to the individual technical chapters in these cases.

#### Title

The title of the report has been changed to emphasize that this volume is a literature review only.

#### Foreword

Because of confusion on the part of several reviewers about the scope and purpose of the report, a Foreword specifically addressing those areas has been added. In brief, the Foreword describes the EPA requirement that probabilities be used in performance assessments and NRC's role in evaluating CCDF's and their contained probabilities. It goes on to state that this report, a literature review, is an initial effort in the area of determining how best to assign probabilities. Finally, it points out that no endorsement of any technique discussed is implied.

#### Executive Summary

About 5 pages of material has been added to the section summarizing Chapter 1, Introduction. Some of this material more explicitly states the goals and purposes of this report and the role of this literature review in meeting NRC's overall need for techniques to evaluate probabilities assigned by DOE in its performance assessments. The reason for choosing the topics of the technical chapters, i.e., their roles as initiating events, is plainly stated, and the difference in treating rare events and continuous processes is noted.

#### Introduction

A sentence has been added to the abstract to emphasize that the present volume is a literature review.

Draft p. 1-2 has been reorganized to emphasize the importance of ultimately reaching some consensus on how to assign probabilities.

About 3 pages of material has been added before the section "Goals" on draft p. 1-3. The first paragraph states that this report is a literature review, and hence has been subject to the vagaries of what has been treated in the literature. Reviewers have correctly pointed out that some chapters do not give details for implementing certain techniques, that other chapters seem at first glance not to be closely related to repository performance, and so on. This paragraph is in response to such comments.

The second paragraph differentiates between this volume and a second volume to come, which will select and illustrate certain of the techniques described here.

The third paragraph differentiates events from processes and points out that they may be treated differently.

A new section, "Using Probabilities in Performance Assessment," more clearly delineates the ultimate use of techniques discussed in this literature review. The most important point made in this section is that the events and processes chosen for inclusion in this report (with one exception) are those which previous workers in scenario development have considered to be capable of initiating the release of waste from a repository. Thus the function of the events and processes in repository performance, not the techniques available for their mathematical treatment, has been the guiding criterion for inclusion in this report.

A paragraph has been added to the section "Goals" to delineate a few items that are beyond the scope of the report, although not every request in the review comments that is beyond the scope has been included here.

### Executive Summary

#### LLNL's Comments

##### General

1. All authors have had the opportunity to edit their sections in the Executive Summary, and the appropriate changes have been made.
2. Changes to the chapters are reflected in the Executive Summary.

##### Specific

1. The figure in question was incomplete in the draft; it has since been completed, and each author has been given the opportunity to review it.
2. The material added to the Foreword, Introduction, and Executive Summary and the disclaimer added to the first page of each chapter should make it clear that neither the NRC nor Sandia endorses any developmental work suggested by individual authors.
3. The paragraph has been changed to soften the implication that earthquake prediction is very accurate.

## Chapter 1. Introduction

The previous section described extensive changes in the Introduction that came about primarily in response to comments on other chapters. This section responds to comments on the Introduction itself.

### Keith I. McConnell's Comments

3. How to treat excessively large residual uncertainty is beyond the scope of this report. Another Task under this FIN will deal with uncertainty.
4. This difficulty is somewhat semantic: all probabilities are an indication of a greater or lesser absence of data. However, this paragraph does not divided probabilities into the meaningful and meaningless, as suggested by the reviewer. It divides them into objective and subjective, totally different categories. When an expert says, "I think so" or "I think not," that is surely meaningful, even though subjective.

### Williams & Associates' Comments

1. We checked the discussion of edf's with two experts in probability and statistics, who said the statement is correct as it stands. We might point out that whether observations are "usually" presented in some other form is immaterial to our original statement.
6. This comment seriously misrepresents the paragraph in question. The paragraph tells what the frequentist approach is and cites both advantages and disadvantages in using it. It says nothing whatever about "background philosophy" of analyzing data, nor does it suggest or imply that all data can be treated equally. Furthermore, two criticisms of the frequentist approach (that the number of data needed depend on the system and that the analyst cannot know whether a new trial will produce a new result) are presented as Williams' ideas, when in fact they are taken verbatim from the paragraph itself!
7. This is the same as comment 1; we have checked with experts, who tell us our usage is correct.
8. As stated several times above, this report does not endorse anything--it reviews the literature. The NRC must know what is in the literature in order to make an informed judgment about whether DOE is using appropriate techniques. Our ignoring a technique will not prevent DOE from using it.
9. See response to comment 8. The material in question has been slightly reorganized to clarify it.

### Unknown Reviewer--reduced and marked-up copy of draft (some comments are illegible on our copy)

- p. 1-5. We agree that thought should be given to how decisions will be made using probabilities, but such a discussion is beyond the scope of this report.

- p. 1-7. This typographical error has been corrected.
- p. 1-20. Another task under this FIN will discuss in detail methods for dealing with uncertainty.

Themis P. Speis's Comments

We appreciate the positive feedback in the introductory paragraph.

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3. Another task under this FIN will discuss in detail methods for dealing with uncertainty.
2. A discussion of whether requirements of 40 CFR 191 are appropriate or not is beyond the scope of this report.

LLNL, Comments on Chapter 1

General

Much material has been added to Chapter 1 (described above) in order to phrase the problem clearly.

- p. 1, line 7. This typographical error has been corrected.
- p. 1, line 26-29. The sentence in question does not suggest that the only use of expert opinion is to substitute for pdf's. The role of expert opinion is discussed at length elsewhere in the Introduction.
- p. 1-8. The role of the expert is discussed at greater length elsewhere in the Introduction, where the material has been rearranged from the draft to clarify it. In essence, by the time a performance assessment must rely on expert judgment for probability assignment, the input is the result.
- p. 1-9, line 10. For the purposes of this literature review on techniques for probability assignment, "consequence" is fairly nebulous; however, the "expected value of some measure" is not consequence, it is risk, as risk = probability x consequence.
- p. 1-9, line 17-18. This paragraph does not suggest that experts should be "allowed to make decisions on what is important," only that expert opinion might be useful in estimating probability.
- p. 1-9, 7 lines from bottom. This comment does not call for a change in the text.
- p. 1-10, last line. We disagree; geologic events are not random for precisely the reasons given in the next 4 lines, top p. 1-11.
- p. 1-11, line 1-4. See previous comment.
- p. 1-11, lines 4-7. The reviewer has not suggested an example in which the statement is not true; we have left the text unchanged.

- p. 1-11, lines 13-15. "Accuracy" and "precision" are used as defined in dictionaries, i.e., "accurate" means "correct" and "precise" means "repeatable." The paragraph on PRAs has been modified slightly and moved to clarify its relevance to the rest of the chapter.
- p. 1-13, line 14. This comment does not call for a change in the text.
- p. 1-15. Characteristic models are discussed in the new chapter on seismic hazard.

#### Gary Sherman's Comments

Sherman's comments on the Executive Summary and Introduction do not call for changes to the text.

#### LLNL's Comments

- p. 1. This page does not call for changes to the text.
- p. 2, lines 1-10. Assessing the presence or absence of a specific geologic feature is the function of site characterization and is beyond the scope of this report.
- p. 2, lines 11-20. Ground motion is discussed in new Chapter 8, Seismic Hazard Assessment.
- p. 2, lines 21-end. How to deal with uncertainty is the subject of another task under this FIN.

### Chapter 2. Resource Exploration

Apparently the author, Sandia, and all the reviewers agree that predicting resource exploration is a particularly intransigent problem, which the author has analyzed reasonably well. Probably for this reason, the comments on this chapter tend to be analytical, rather than to call for specific changes. Very little literature is available that assists in forecasting human intrusion over the time periods in question, so the author has concentrated on the kinds of analyses that would be necessary. The difficulties of prediction are the reason for including a discussion of the EPA's and NRC's guidance on treating human intrusion, a section without parallel in the other chapters.

#### Charlotte Abrams's Comments

This comment does not call for any changes to the report, instead pointing out the difficulty of evaluating future exploration's effect on the repository. We agree, as does the author of the chapter.

#### Terrance Anstett's Comments

Our draft of the chapter has the phrase "This chapter considers procedures for estimating..." We cannot find the phrase "establish procedures..." We agree that "establish" is the wrong word and will do an automated search to

ensure that it is out of the final draft in the context of stating the objective of the chapter.

Anstett's first and third comments do not call for any change in the text.

#### Gary Sherman's Comments

##### Specific

Comments on p. 2-12, 2-26, and 2-31 are largely in agreement with the chapter about the difficulties of predicting exploration and therefore do not require changes.

P. 2-33 does not imply that the URV approach could "substitute" for drilling by providing the same information as drilling, but rather that if drilling is infeasible (e.g., because large-scale drilling might make the site unsuitable, as pointed out by Abrams), then URV might be used to gain some insight.

##### General

This comment does not call for changes. Rather it reiterates the difficulties in predicting human intrusion and states that the the chapter treats the subject adequately.

#### Thomas Gunther and Barbara White's Comments

##### General and Economic Forecasts

The commenters state that the general approach seems appropriate, but that the author has not provided implementation details. This is because the literature does not contain implementation details.

##### Technological Forecasting

The material mentioned in this section is substantially beyond the scope of this chapter.

##### Resource Assessment Methods

The point that URV indicates past activity, not future activity, has been made in the report.

##### Other Comments

1. It is beyond the scope of this report to assemble data or to plan data-collection programs. The most reliable method of gaining site-specific data, i.e., drilling, has been discussed, but drilling has its drawbacks.
2. Few alternative approaches are available in the literature. Cost and benefit analysis is beyond the scope of this report.



3. Discussion of possible societal changes is far beyond the scope of this report. Apparently the writers of the EPA and NRC regulations believed such an exercise to be of limited value; EPA and NRC guidance for assumptions in this area have been discussed in the chapter.

The remaining comments reiterate the discussion of the previous pages.

LLNL's Comments

- p. 1 through middle p. 4. These pages summarize the chapter without calling for changes.
- bottom p. 4. It is true that the author has concentrated almost exclusively on drilling and has not considered mining. Mining at such great depth is typically preceded by drilling, however, and the EPA Standard, Appendix B suggests not only that drilling can be the most severe human intrusion considered in a performance assessment, but also that drilling will reveal the repository to the intruders. We think that guidance tends to diminish the importance of mining as a breaching mechanism of regulatory interest.
- p. 5, para. 2. Data on drilling more than a few years in the future are not "limited," they are nonexistent. For this reason, the author is correct in concluding that an objective probability of intersecting the repository envelope can not be obtained.
- p. 5, para. 3, p. 6, paras. 1 & 2. The reviewers correctly summarize the author's position that only subjective probabilities can be obtained for future drilling, but they go on to disagree, saying that experts could provide objective probabilities. They give as an example a report on predicting seismic hazard. Seismic processes can be expected to be largely stable over the next 10,000 years, however, whereas the technology for resource exploration in the past has sometimes remained stable for as little as a decade. We repeat, there are no objective data on future drilling, and therefore the probabilities can not be made objective.
- p. 6, para. 3. The discussion of regulatory guidance was included in the draft for the reasons that the reviewers point out here.

*Comments on  
chapters 3, 4, 5 have been  
removed because those chapters  
are no longer in the report.*

## Chapter 6. Climatology

### LLNL Review

#### A. General

1. Summarizing the findings of all previous efforts in paleoclimatology and comparing these with model results is far beyond the scope of this report. Material added to the Introduction and Foreword should clarify this.
2. We agree that figure quality in the drafts has been poor. The figures will be of better quality in the final report, although some of the figures were not very good in the original journals.
3. The chapter has been reexamined in light of this comment. For the specific example given, "initialize" does not mean simply "begin" in this context; it is a word commonly used to describe the process of getting a data set and computer code ready to run.

## B. Specific

1. We supplied p. 6-2 to the NRC.
2. Examples of free and forced variables have been added to the sentence in question.
3. This is an introductory paragraph that uses the general behavior of ice sheets as an example. The detail suggested in the comment would be inappropriate. In any case, the paragraph does not refer to ice-sheet behavior as a constant at the time scale in question, but only as an external control because of its long response time.
4. This paragraph does not present past temperatures as a progression, but rather as observed data. The existence of an upper limit (if any) is immaterial to the discussion.
5. This comment does not call for any change to the text.
6. See the response to comment 4.
7. The modeling and validation effort discussed on these pages is presented as a "potential strategy," not as a necessity. Determining the need for implementing the strategy is beyond the scope of this report.

## Joel Grimm's Comment

The authors were asked, as explained above, to identify and evaluate any existing techniques for assigning probabilities. If no techniques exist, and the authors say that, it is surely quibbling to suggest that they have fallen short of the goal. In any case, the authors of Chapter 6 have suggested a means of assembling a predictive methodology from existing tools.

## Chapter 7, Tectonics and Seismicity

### A. Ibrihim's Comments

#### Reviewer 2, p. 1

The reviewer correctly states the purpose of the report but states that Chapter 7 falls short of addressing each Purpose (in contrast to Reviewer 1, who felt that each chapter met its goals). We disagree. Pages 7-4 through 7-24 review the existing techniques and explicitly evaluate their merits and limitations. Pages 7-28 through 7-30 propose modifications to existing techniques and recommend an approach.

- p. 2. Seismic hazards are addressed in the new Chapter 8, Seismic Hazard Analysis, by Allin Cornell.
- p. 3 and 4. Most of the topics mentioned on these pages are discussed in new Chapter 8.

### Reviewer 3

Many of Reviewer 3's comments are illegible on our copy; we requested but did not receive a better copy. In addition, many of the markups are comments not calling for changes. We made changes as follows:

top p. 7-20. The paragraph now refers the reader to new Chapter 8.

top p. 7-23. The sentence has been clarified to eliminate the implication that Brown discussed repository sites.

### Unknown Reviewer, AI/86/06/23

These comments have been addressed in full by including new Chapter 8.

### Themis P. Speis's Comments

4. Material added to the Foreword and Introduction and the disclaimer added to the first page of Chapter 7 should make it clear that no endorsement of the EPRI method is implied.
5. The material discussed on these pages is in fact about earthquake prediction, i.e., the specific occurrence in time and space of a specific earthquake, so the correct terminology has been used. Seismic hazard, i.e., "what damage will occur if an earthquake happens?", has been fully addressed by the inclusion of new Chapter 8, Seismic Hazard Assessment.

### Michael Blackford's Comments

- p. 1. No changes are called for.
- p. 2, para. 1. No changes are called for.
- p. 2, para. 2. What is meant by earthquake prediction is clearly stated immediately above the subtitle "Earthquake Prediction."
- p. 2, paras. 3 & 4. No changes are called for.
- p. 3. The application of the EPRI method is also discussed in new Chapter 8.

### Keith I. McConnell's Comments

#### Executive Summary (actually Ch. 7)

1. The basis for the statement that the data are of high quality is referenced in detail in the section on data bases in Chapter 7 per se.
2. Reactivation of basement structures in seismically active areas certainly could have been discussed in this chapter, but the constraints of time and money limited the scope of the chapter, as well as the report as a whole.

- p. 1, para. 2. The EPA Standard explicitly endorses the use of expert judgment. Outlining the qualifications for expertise is beyond the scope of this report, however.

Specific Comments

1. "Establish" has been changed to "illuminate."
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3. After consideration, the text was left unchanged.
4. The suggested change has been made.
5. "Crack" is more general than "joints"; the text has been left unchanged.
6. This approach is presented only as one that is feasible (as indicated by the changed section title), not as one that will necessarily reduce uncertainty.

LLNL's Comments

General

1. This positive comment on Chapter 7 does not call for changes in the text.
2. Microseismic networks and remote sensing certainly could have been discussed in this chapter, but the constraints of time and money limited the scope of the chapter, as well as the report as a whole.

Specific Comments

1. Both the types of prediction mentioned in this comment are discussed in the chapter. We have reviewed the material and find that the distinction between them is fairly clearly made in the chapter.
2. Other sections of the chapter discuss earthquakes that are not accompanied by surface rupture.
- 3, 4 &
5. These comments do not call for changes in the text.
6. The point that precursors are not particularly reliable has been made in the section "Assessment."
7. The suggested change has been made.

Additional Comments

- p. 7-1. The sentence in question states that the geology of the site is fundamental, not that it is the only important field to consider. The second paragraph of the chapter's Introduction refers to whole-earth, regional, and local processes, as does the body of the chapter.

- p. 7-2. This chapter is not written from the point of view of the earthquake engineer. The addition of Chapter 8, Seismic Hazard Assessment, should address this comment in full.
- p. 7-3. The sentence in question does not suggest that study of a smaller area neglects distant events that affect that area.
- p. 7-5. This comment does not call for a change in the text.
- p. 7-19. After consideration, we left the text unchanged, on the basis that ground motion has a source, not a "potential" source.
- p. 7-21. This comment seems to be unrelated to the page and line given, so we are unable to respond.
- p. 7-23. (a) The effects and consequences of ground motion are discussed in new Chapter 8, Seismic Hazard Assessment. (b) The sentence in question has been clarified. (c) This point is already made in the sections "Limitations" and "Assessment."
- p. 7-27. The reference is too incomplete to be useful.
- p. 7-25. The sentence in question does not say that the method is inadequate because it is uncertain, it says that the method is inadequate to provide great certainty. The text has been left unchanged.
- p. 7-29. This comment does not call for changes to the text.

#### Chapter 8, Volcanology (Now Chapter 9)

##### WMGT Review

Comments written at top (t.) and bottom (b.) p. 8-4, t. p. 8-6, t. and b. p. 8-7, t. p. 8-10, t. p. 8-14, t. and b. p. 8-19, and b. p. 8-20. Each of these comments suggest that the techniques discussed by McBirney be carried out at the 3 DOE sites under investigation. Presumably, considering the reference in comments on p. 8-19 to BWIP, the reviewer means that DOE should use these techniques in their performance assessments. It would be far beyond the scope of this report to apply the techniques to site-specific data and present the results in this chapter. Material added to the Introduction should clarify this.

Typo, p. 8-4, line 9. This typographical error has been corrected.

Comment written at b. p. 8-14. The sentence in question has been repunctuated to make it clear that Watkins and Baksi, 1974, are the source. We have no way of knowing whether Johnpeer and others, 1981, were aware of this result or not.

##### Charlotte Abrams's Comment

We appreciate this positive feedback on Chapter 8.

## LLNL's Comments

### General

We agree that figure quality in the drafts has been poor. The figures will be of better quality in the final report, although some of the figures were not very good in the original journals.

### Specific

1. We have reviewed the paragraph, and we think that "the approach ... uses the past record of activity and extrapolates trends..." is a very clear statement that trends will be incorporated. The text has been left unchanged.
2. This comment reiterates the text and therefore does not call for changes.
3. A detailed review of the data on a particular type of volcanism is beyond the scope of this report. Incidentally, as stated in the text, this type of volcano is so rare that it is probably not of regulatory interest, as suggested by Appendix B of the EPA Standard.
4. A detailed review of the data on a particular type of volcanism is beyond the scope of this report.
5. There has been no particular effort to make any of the chapters self-contained; ~~to~~ do so would mean adding a great deal of repetitive material to an already lengthy report.
6. Given that none of DOE's current sites are in areas where precursory phenomena would be significant, the suggested material would not add to the usefulness of the report.