United States Department of the Interior

BUREAU OF MINES
2401 E STREET, NW.
WASHINGTON, D.C. 20241

86 JUL -2 P9:49

June 27, 1986

Memorandum

To: Charlotte Abrams, Project Officer, Geotechnical Branch
Division of Waste Management, U.S. Nuclear Regulatory Commission

From: Ransom F. Read, NRC Program Manager

Subject: Review Comments Re Sandia National Laboratories Report Entitled "Techniques for Determining Probabilities of Events and Processes Affecting the Performance of Geologic Repositories."

The Bureau of Mines' review comments to the subject Sandia Laboratories report are attached. Please contact the Bureau reviewers directly if additional explanation is required. They are:

Terrance Anstett
Minerals Availability Field Office
Building 20, Denver Federal Center
Denver, Colorado 80225
(303) 236-4856

Gary Sherman
Alaska Field Operations Center
P.O. Box 550
Juneau, Alaska 99802
(907) 364-2111

Tom Gunther or Barbara White
Division of Minerals Policy Analysis
Washington, D.C.
(202) 634-1293

Ransom F. Read
Ransom F. Read

WM-RES
WM Record File D1018 BOM
WM Project 10,11,16
Docket No.
PDR ✓
LPDR ✓ (B,N,S)

Distribution:
xAbrams
(Return to WM, 623-SS)

3166

6/26/86

Review of
Techniques for Determining Probabilities of
Events and Processes Affecting the Performance of
Geologic Repositories

With respect to those portions of the subject report that I have been asked to review, I have the following comments:

- The Executive Summary (Hunter and Mann) and Introduction (Hunter, Mann, Conover, and Budnitz) generally provide a satisfactory, comprehensive review and discussion of probabilistic methodologies.

- Chapter 2 (Harbaugh) is a good explanation of probability trees and possible approaches to resource-value determinations for test sites, but does not accomplish the stated objective (i.e., "...to establish procedures for estimating the probabilities of breaching HLW repositories by resource exploration or exploitation activities within the next 10,000 yr."). Unfortunately, I view the task as virtually impossible, and have no suitable alternative recommendations.

- I agree with Harbaugh's conclusion that a series of exploratory drill holes is the best method to assess the resource potential of proposed sites, but am skeptical of the usefulness of incorporating the unit-regional value approach he describes. In order to use the URV approach as described, it is necessary to acquire enough site-specific geologic/deposit information with which to identify a suitable geologic analog (i.e., area of substantially similar geology/deposits for which the URV is known) in order to establish a URV for the test site. How is this site-specific information to be acquired? Site specific geologic/deposit information of sufficient quality to be of use in a geologic-analog URV appraisal could be used to generate an independently-derived (i.e., not analog-based) value for the site, an approach that I recommend. Because of my skepticism regarding the implicit assumptions incorporated in a URV appraisl based on geologic analog (e.g., level of past socioeconomic activity of an analog site is assumed to apply in the future at the test site), I would rather see independently derived resource (URV) figures for each test site.

Terrance Anstett
Minerals Availability Field Office
Building 20, Denver Federal Center
Denver, Colorado 80225
(303) 236-4856

6/26/86

Review and Comments on sections of Sandia National Laboratories Report "Techniques for Determining Probabalities of Events and Processes Affecting the Performance of Geologic Repositories."

The primary objective of the relevent portion of the study is to project exploration activity and integrate such projections with other information, specifically the "probability envelope" describing the extent of radioactivity over the forecast horizon. The desired result of the study is the ability to estimate the probability that exploration activity will cause the release of radioactivity into the environment. Study parameters and assumptions include: a 10,000 year forecast horizon; minimum levels of likelihood that would cause an event to be included in the study; and the continuation of society at minimum levels of civilization. This review assumes the availability of forecasts of the probability envelope, and focuses on the issues of resource assessment and mineral exploration activity.

The approach suggested in the study implicitly includes four major components: forecasts of the economic desirability of mineral commodities; forecasts of mineral deposit detection and exploration technologies; assessments of the resource potential in the areas in question; and forecasts of the level of exploration and exploitation activities. This general approach seems sppropriate, and reflects the major elements that would influence the probability of a breach. The author addresses each of these topics and suggests methods or techniques that can be used to obtain the desired forecasts. However, few alternative approaches are identified in a single case, and the need for and availability of data are only lightly treated. Specific criticisms are as follows:

Economic Forecasts:

1. The use of "unit regional value", based on historical production is suggested. Although this approach provides a method for estimating the value of an area, its dependence on historical activity introduces a bias against unexplored or poorly understood regions (e.g. Alaska).

2. It is suggested that "relative demand" be used to forecast the desire for minerals and thus a measure of overall exploration activity. The concept is not well developed, but seems to imply a point estimate of quantity demanded relative to prior periods or overall economic activity. In order to satisfy the objectives of the study, an estimate of demand functions would be more appropriate. In either case, a methodology for developing such forecasts is not discussed, and the use of point estimates would seem to reflect an unwarrented confidence in forecasting abilities.

3. The "exploitability/depth index" is suggested as a method to establish bounds on the depth of deposits to be considered in the study, but again, few implimentation details are provided.

4. There is little treatment of the responsiveness of mineral exploration and exploitation activities to changes in economic conditions. Although the length of the forecast horizon would argue strongly against consideration of short-term fluctuations in resource prices/availability, it seems that short term phenomena such as wars and/or economic craises are more likely to lead to inadvertent breaches than slow growth in resource prices over time.

Technological Forecasting

1. Very little attention is given to technological forecasting. The length of the forecast horizon and technological progress over the last 100-500 years suggests that the demand for fuel and non-fuel mineral aresources (or more exactly, the properties that they impart to products) will be increasingly met by non-traditional means including synthetic materials, seabeds, asteroids and moons, as well as changes in demand resulting form fundamental changes in life styles.

2. There is little or no discussion of the technologies of deposit detection and mining and the potential for improvements in the near to medium term. In situ burning of fuels for example, may make deep coal deposits (not now included in resource estimates because of their depth) exploitable in the relatively near future. Satellite technologies such as synthetic aperature radar may help identify geologic features and suggest deposits in otherwise unpromising areas.

3. The interaction of economics, and the technology of resource extraction and utilization is not addressed. For example, developments in processing and refining methods may "create" resource deposits in the sense that they are suddenly economicallyl feasible; the discovery of previously unknown types of deposits may result in the development of the technology necessary to exploit them; and improvements in waste recovery and recycling technologies may reduce demand for virgin resources.

Resource Assessment Methods and Projected Exploration Activity

1. Little mention is made of alternative resource assessment methods although considerable effort has been expended in this area in the U.S. Geological Survey and the Bureau of Mines.

2. Unit regional value and similar concepts are indicators of past attractiveness of an area, but are poor indicators of future attractiveness since exploration is more likely driven by e.g. geophysical and geochemical anomolies.

Other Comments

1. More consideration should be given to currently available data and the requirements for new data collection efforts. In some cases, it would seem that the only way to obtain the necessary data is by methods which would reduce the desirability of the site as HLW site. In other cases, it seems unlikely that the data can be obtained under any circumstances.

2. Few alternative approaches for the various components are developed, and costs and benefits of alternatives are not discussed.

3. With the exception of the "true" geologic state of nature, all of the issues that affect the likelihood of mineral exploration activity are derived from broad developments in society and the advancement of knowledge in multiple disciplines. Even with the NRC stated boundaries on societal changes (e.g. ignoring nuclear war and general collapse scenarios), there is still an enormous range of possible outcomes that can completely determine mineral exploration activity. Ignoring even extreme outcomes such as the transmutation of elements (and therefore no need for mining) is not justified given the 10,000 year forecast horizon. While this point is not a specific criticism of the work of the author, it does suggest that a much broader approach to the issue is necessary, and that the implicit constraints adopted by the author are likely to lead to estimates that reflect a much greater degree of certainty than is justified.

To facilitate the identification and evaluation of quantitative methods for determining the probabilities of events and processes associated with exploration activity which might result in the breaching of a HLW respository, it is useful to ennumerate the types of issues with uncertain outcomes which must be addressed:

1. What is the likelihood that undiscovered mineral deposits exist in the area of the responsitory site (or which may be formed over the next 10,000 years)? In what forms and at what depths might they occur?

2. What is the likelihood that society will demand quantities of minerals such that exploration and development of deposits such as those in the respository area will occur?

3. What is the likelihood that technology will have advanced to the point that the deposits thought to exist in the area can be detected, mined and recovered?

4. What is the likelihood that exploration for and development of the deposits will result in intersecting of the probability envelope as described by Dr. Harbaugh?

Issue 1 is a geoscience question, independent of the technology and economics that may influence future exploration and development. Description of the resource endowment must be in a form that allows subsequent analyses to be performed. The accuracy of such descriptions would, of course, be subject to available geologic data. Because a) the existence of mineral deposits is a site specific phenomenon; b) deposits are invisible until discovered; and c) objective data concerning the number, types, sizes, grades, locations and depths of undiscovered deposits do not exist, some form of subjective judgement or delphi process must be used to elicit probabilistic estimates for those endowment descriptors which are needed for subsequent analysis. Such descriptors would include: the likelihood that deposits are present; the conditional distribution of the number of deposits; distributions of sizes of deposits; the metals or other resources contained in the deposit; present; distributions of the grade or "richness" of the deposit; and distributions of the depths of the deposits. The USGS has developed world-wide grade and size models for over 100 types of hard rock mineral deposits, and similar information and models are available for hydrocarbons. Such models have been used in the past

by the USGS and the BOM in endowment modelling, and, although several problem areas remain, these could be applied to the issues facing the NRC.

The probabilistic endowment descriptions that are the output of such models would provide one input for projecting the relative attractiveness of an area and the likely exploration and development activity that would occur over the future. This information, in turn, would be used to estimate the probability that the probability envelope wold be breached.

Additional necessary analytical components include technological and economic forecasting, and an exploration and discovery model. Technological forecasting has been utilized successfully in numerous application areas. In this case the objectives would include forecasts of technological improvements in the ability to detect or explore for deposits (particularly at incresingly greater depths), in the ability to mine deep deposits, and the ability to recover resources from low grade deposits. However, the long forecast horizon makes almost any imaginable technology potentially feasible, and casts additional doubt on the usefulness and validity of the exercise. Similar reservations would apply to economic forecasting which is seldom accurate for more than 2 to 3 years into the future. An exploration and discovery model is under development at the BOM, and will utilize economic forecasts and, to a lesser degree, projected technological improvements. Given the existence of the long term forecasts required by the NRC, the model may provide the information necessary to estimate the probability of breaching the HLW probability envelope.

In summary, while tecnniques exist and/or are being developed to address many of the component issues, few retain believability when applied over longer forecast horizons. Probably the least problematic of the areas is the estimation of resource endowment, although it too is subject to considerable error. Fundamentally, the exercise requires societal forecasts (economics, technology, sociology, etc). Although some scenarios (e.g. in which knowledge or radioactivity and its dangers has been lost) have been specifically excluded, others which involve loss of geologic knowledge or mining ability, or those involving a resource poor and earthbound society, have not. The number of factors affecting the probability of breaching a probability envelope, and the length of the forecast horizon seem to preclude any useful forecasts.

If there are any questions or comments on this material, please call either Thomas Gunther at 634-1289 or Barbara White at 634-1293.

Comments on Sandia National Laboratories Report Entitled
"Techniques for Determining Probabilities
of Events and Processes Affecting
the Performance of Geologic Repositories"

° Executive Summary and Chapter 1:

As stated in the Executive Summary, the purpose of this study was to search out and evaluate existing quantitative methods for determining probabilities of events and processes in eight fields of concern. In addition the project was to identify phenomena for which accurate probabilities cannot be estimated at this time and to identify areas of research that could improve significantly our ability to make estimates in the immediate future.

The overall tone of the Executive summary is that existing methodologies for estimation of relevant probabilities is poor when attempting to predict events in the mid to long range future (1000 to 10,000 years). This is certainly a problem, particularly when attempting to predict human behavior and its interaction with technologic and economic conditions. The report does a good job in reviewing the literature and methodologies used in the past. Evaluation of existing quantitative methods for determining probabilities was found adequate for the chapters reviewed (E, 1, 2).

The report achieves the goals stated in the following manner:

° A cursory review of existing methodology is given which discusses the applicability and/or problems with use.

° The shortfalls of the methodologies, i.e. their inability to "predict" probabilities for events in the future (1000 to 10,000 years) are pointed out. My impression is that, except in rare cases, the ability to make probability estimates for events that far in the future is lacking, given the nature of the required estimates. Due to the lack of data on future human activity, technology advances, and socio-political climates, the estimates become qualitative rather than quantitative.

The report correctly points out that since the EPA requires estimates to be made, the best approach must be defined, presumably on a case by case basis.

- Chapter 2, Resource Exploration:

  - Page 2-12 - Ore deposits are defined as being "economically exploitable". While this is true, the economic feasibility of a deposit has little influence on whether or not the probability envelope of a HLW repository will be breached during exploration. Drilling is done to determine the characteristics of the deposit, that information in turn being used to estimate it's exploitability (economic feasibility).

    Potentially exploitable as used in the report appears to really mean that a commodity will be in enough demand to warrant exploration, development, and production. This point should be clarified in the report.

    Real problems exist in trying to estimate the exploitability/depth index and extrapolating it over a 10,000 year period. While some finite technologic depth exists for the mining of all deposits, the exploitability is very difficult to estimate, since it requires an estimation of future supply demand relationships. Experts have difficulty predicting the price of gold from year to year, let alone attempting to model the future supply-demand (and hence exploitability) 10,000 years from now.

    To predict the future one would have to model all aspects of resource exploration, including the political, economic, and technologic conditions/changes likely to take place over the next 10,000 years. With a data base of past human activity spanning only a few hundred years since the industrial revolution, the task is indeed formidable.

  - Page 2-26 - To estimate the amount of exploratory drilling to be expected in the next 10,000 years requires the estimation of relative demand and the exploitability/depth index, factors which are as abstract as the amount of drilling. The author states this task is formidable, if not impossible, and I agree entirely.

  - Page 2-31 - Conclusions: The conclusions state that objective estimates of mineral resource potential on a unit-area or unit-rock-volume basis are impossible to make when a number of mineral commodities are involved. Predictions for up to 10,000 years in the future are absolutely impossible given present resource estimation technology. The field of

undiscovered mineral resource estimation is still in its infant stages. While much work by various government agencies and universities is underway, the methodology to estimate the parameters required is nonexistent. I agree that future economics of mineral resource exploration cannot be objectively treated nor ignored. While the author states that probability estimates of future economic factors must be largely subjective, I believe that they must be entirely subjective for the time ranges considered.

- Page 2-33 - Recommendations: I think the author's suggestion to perform exploratory drilling around the proposed repository site is reasonable. Locating the repository in a geologic environment which is less favorable for the occurrence of mineral deposits would be a major first step. This assumes of course that geologic materials which we consider to have no industrial use will remain that way in the future. The unit regional value (URV) approach cannot substitute for drilling, as stated by the author.

General Comments

The report does an adequate job of reviewing the methodologies (or at least mentioning them) that exist for resource exploration. Given the problem of estimating probabilities for events which may occur 10,000 years from now, no current methodologies can be directly used. The scope of the model required is mind-boggling: one that would take into account future political, social, technologic, and economic conditions and also be able to simulate random human events which would affect the search for and exploitation of mineral resources. The report points out the problems and difficulties involved, and in the case of resource exploration offers a solution which would provide hard data on which to estimate the likelihood of presence of a mineral deposit in the repository area: drilling.

I believe that the report points out the difficulties involved and defines problems/issues which must be addressed to evaluate probabilities contained in HLW license applications. While the goals of the study are seen as first step toward establishing a quantitative method for determining realistic probabilities of natural processes that will be objective, reproducible, accurate, and universally applicable (Executive Summary, page 2), I have serious doubts as to whether such a system can be developed. Quantitative estimation of events 10,000 years in the future is, in my opinion, impossible for resource exploration and possibly some of the other fields covered by the study. Subjective estimates are always possible, and for events which are rare, may never be proven right or wrong. I believe the type of estimates which will be generated, due to the nature of the problem, will be subjective with a large degree of uncertainty.

Gary Sherman
Alaska Field Operations Center
P.O. Box 550
Juneau, Alaska 99802
(907) 364-2111