PNL-SA-7197

MASTER

Waste Isolation Safety Assessment Program

Workshop on Potentially Disruptive Phenomena for Nuclear Waste Repositories

J. J. Jacobson, Chairman

July 27-28, 1977

Prepared for
Office of Waste Isolation
under its Contract with the
U.S. Department of Energy

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-SA-7197

DISCLAIMER

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract EY-76-C-06-1830

Waste Isolation Safety Assessment Program

WORKSHOP ON POTENTIALLY DISRUPTIVE PHENOMENA FOR NUCLEAR WASTE REPOSITORIES

J. J. Jacobson, Chairman

July 27-28, 1977

Prepared for the
Office of Waste Isolation
under Contract EY-76-C-06-1830
with the U.S. Department of Energy

Pacific Northwest Laboratory
Richland, Washington 99352

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

SUMMARY

The workshop on Potentially Disruptive Phenomena for Nuclear Waste Repositories brought together experts in the geosciences to identify and evaluate potentially disruptive events and processes and to contribute ideas on how to extrapolate data from the past into the next one million years. The analysis is to be used to model a repository in geologic media for long-term safety assessments of nuclear waste storage.

The workshop included invited presentations by specialists who were well known in their respective areas of interest. They spoke on the following items:

1. an overview of the Waste Isolation Safety Assessment Program (WISAP)
2. simulation techniques
3. subjective probabilities and methodology of obtaining data
4. similar modeling efforts at Lawrence Livermore and Sandia Laboratories
5. geologic processes or events.

At the close of the workshop, the participants were asked to write brief reports outlining their approach to providing information and data for the analysis of the potentially disruptive events.

ACKNOWLEDGMENTS

This report was prepared by the Pacific Northwest Laboratory under subcontract TDO-918 with the Office of Waste Isolation, a division of Union Carbide Corporation and contract #W-705-eng-26 with the U. S. Department of Energy.

We wish to thank Pidge Eastland, Jody Marshall, and Julie Swor of Battelle for their help in conference organization and logistical support. We are grateful to the rest of the Battelle-Seattle conference staff who were responsible for lodging, food, and audio-visual services.

We are grateful to the Office of Waste Isolation, a division of Union Carbide, for their monetary support and technical assistance. Three individuals in particular strongly supported and aided PNL's efforts: Dr. Lester R. Dole, Dr. H. Clyde Claiborne and Dr. William C. McLain.

Finally, the effort of guest speakers and attendees--whose participation led to lively discussions, program direction and guidance--is much appreciated.

CONTENTS

AGENDA

WEDNESDAY, JULY 27, 1977

8:15	Call to Order - Announcements
8:30	WISAP Overview, H. C. Burkholder (PNL)
9:00	Repository Simulation Presentation, J. A. Stottlemyre (PNL)
10:15	Coffee
10:30	Preliminary Efforts and Present Status, J. A. Stottlemyre (PNL)
11:45	Discussion
12:00	Lunch
1:15	Subjective Probabilities and Questionnaire Development, L. H. Wight (TERA)
1:45	Review of Program Efforts at Livermore, T. Holdsworth (LLL)
2:30	Coffee
2:45	Review of Program Efforts at Sandia, M. Tierney (Sandia)
3:30	Individual Presentation: Subject Area: Paleoclimatology and Meteorology, G. J. Kukla (Lamont)
4:00	Physical Oceanography, M. L. Schwartz (WWU)
4:30	Glaciology, C. B. B. Bull (OSU)
5:00	End First Day

THURSDAY, July 28, 1977

8:15	Call to Order - Announcements
8:30	Salt Dissolution/Erosion/Sedimentation, J. D. Martinez (LSU)
9:00	Uplift/Subsidence - Gulf Coast, R. L. Thoms (LSU)
9:30	Surface and Subsurface Hydrology, W. W. Wood (USGS)
10:00	Volcanism/Igneous Intrusions, B. M. Crowe (LASL)
10:30	Coffee
10:45	Seismology (given by L. H. Wight, TERA), G. Frazier, Del Mar Technical Associates
11:15	Meteorites, W. K. Hartman (PSI)
12:00	Lunch
1:15	Non-Salt Areas, F. A. Donath (IU)
2:00	Discussion
2:30	Coffee
3:00	Round Table Discussion and Recommendations
5:00	End Workshop

INTRODUCTION

Safe storage of radioactive waste material is a necessity for the continued use of nuclear power. The Waste Isolation Safety Assessment Program (WISAP) was initiated by the Energy Research and Development Administration (ERDA) and is being continued by the Department of Energy (DOE). WISAP is administered for DOE by the Office of Waste Isolation (OWI), a division of Union Carbide Corporation. The primary objective of WISAP is to assess the safety associated with long-term disposal (isolation) of nuclear wastes in a geologic formation. To achieve this objective it is necessary to develop methods and to generate data which will characterize the safety of a geologic waste disposal site.

Comprehensive safety analyses for geologic isolation repositories have six elements:

1. identification of events and processes which could potentially cause breach of containment at the repository cavity
2. analysis of the ways these phenomena could combine to cause containment breaches
3. quantitative description of the radioactivity release scenarios
4. prediction of radionuclide release rates from the repository cavity
5. prediction of the transport of released radionuclides to man
6. prediction of radionuclide interaction with man.

The first three items, which focus on the prediction and description of repository release scenarios, were the basis of a workshop held at the Battelle Seattle Research Center (BSRC) in Seattle, Washington, July 27 and 28, 1977. Items 4 through 6 deal with consequences of a release and will be discussed in a separate workshop report (Raymond 1978). The workshop discussed in this report was held in order to bring together specialists to evaluate a list of potentially disruptive events or processes. These specialists were asked to present their ideas on how the events or processes could be described and quantified for the simulation analysis, and to engage in peer review and interaction on the various elements.

The workshop was organized on the following basis:

1. an overview of WISAP
2. repository simulation, technique and status
3. subjective probabilities and methodology for obtaining information
4. similar programs at Lawrence Livermore Laboratory and Sandia Laboratories
5. geologic processes or events:
   - paleoclimatology and meteorology
   - physical oceanography
   - ice age processes or glaciation
   - salt dissolution/sedimentation/erosion
   - uplift/subsidence, Gulf Coast areas
   - surface and subsurface hydrology
   - volcanism/igneous intrusions
   - remote seismology
   - meteorites
   - hydrology - nonsalt areas

WORKSHOP CONCLUSIONS AND FUTURE WORK

The workshop indicated that the following areas require continuing study and analysis:

- Coastal Geomorphology and Sea Level Fluctuations
- Glaciology
- Tectonism
  - Pacific Northwest
  - Southwest
  - Gulf Coast
- Geomorphology and Surface Hydrology
  - Pacific Northwest
  - Southwest
  - Gulf Coast
- Subsurface Hydrology
  - Pacific Northwest
  - Southwest
  - Gulf Coast
- Volcanology
- Remote Seismology
- Meteorites

The Office of Waste Isolation requested, in addition, the study of man-caused events. The participants were requested to submit proposals on continuing their studies; six responded and were funded for continuing studies. Ten additional consultants were obtained to cover the remaining areas. Table 1 lists the study areas funded in FY-78, the consultants and their affiliations.

TABLE 1. Study Areas of Potentially Disruptive Events, Consultants and Their Affiliations During FY-78

Study Areas	Consultants	Affiliation
Glaciology	C. B. B. Bull	Ohio State University
Meteorology	G. J. Kukla	Lamont Doherty Geological Observatory
Coastal Geomorphology Sea Level Fluctuations	M. L. Schwartz	Western Washington University
Volcanology	B. M. Crowe	Los Alamos Scientic Laboatory
Meteorites	W. K. Hartman	Planetary Sciences Institute
Geomorphology and Surface Hydrology:		
Southwest	S. J. Mara	Stanford Research Institute (SRI) International
Pacifc Northwest	D. W. Tubbs	Rodger Low Assoc., Inc.
Structural Geology:		
Southwest:Waste Isolation Pilot Project (WIPP) Area	J. M. Hills	University of Texas, El Paso
Southwest; Basin and Range Area	E. M. Lovejoy	University of Texas, El Paso
Gulf Coast	R. O. Kehle	Turk, Kehle and Assocites
Pacific Northwest	H. A. Coombs	University of Washington
Ground-water Hydrology:		
Southwest	S. N. Davis	University of Arizona
Pacific Northwest	M. D. Veatch	Shannon and Wilson
Remote Seismology	L. H. Wight	Teknekron Energy Resource Analysis Corporation (TERA)
Man-Caused Events	R. D. Gastil	Freedom House
	B. J. Smernoff	Hudson Institute

SUMMARIES OF TECHNICAL PRESENTATIONS

The following discussions represent summaries of the technical papers presented by the consultants during the workshop. It should be noted that these summaries are edited from written reports or transcriptions of the presentations, and hence, are not verbatim.

SUBJECTIVE PROBABILITY AND QUESTIONNAIRE DEVELOPMENT - Larry Wight, TERA Corporation

Many decisions are based on beliefs concerning the likelihood of uncertain events such as technology forecasting, the psychological response to stimuli, or the future value of the dollar. Often these beliefs concerning uncertain events are expressed in numerical form as odds or probabilities. These quantified expressions of opinion are called subjective probabilities. The present plan for development of input to the WISAP Disruptive Event Analysis is to solicit the advice and judgment of selected experts. Possible biases in their judgment can be removed and the credibility of the program can be enhanced if subjective probability analysis is properly applied.

Opinion Biasing

Biases in opinion, particularly expert opinion, are very common and dangerously subtle. In developing an opinion, experts rely on a limited number of heuristic principles which tend to simplify their assessment process but can also lead to severe and systematic errors. These principles can be categorized as:

representativeness

availability

adjustment and anchoring

Representativeness is an approach in which general characteristics of a group are applied to a specific member of a group. This approach ignores the fact that group characteristics will vary and that there is a significant probability that any member will have characteristics differing substantially from the group norm.

There are situations in which people assess the frequency of a class or the probability of an event by the ease with which instances or occurrences can be brought to mind. This judgmental heuristic is called availability. Availability is a useful clue for assessing frequency or probability; however, availability is affected by factors other than frequency and probability. Consequently, a reliance on availability leads to unpredictable biasing.

Adjusting occurs when estimates are made by starting from an initial value that is adjusted to yield the final answer. The initial value, or starting point, may be suggested by the formulation of the problem, or it may be the result of a partial computation. In either case, adjustments are typically insufficient.

Anchoring occurs when the starting point alone is used by the subject, and the estimate reflects little or no adjustment. In decision analysis, experts are often required to express their beliefs about a quantity, such as the value of the Dow-Jones average on a particular day, in the form of a probability distribution. Such a distribution is usually constructed by asking the person to select values of the quantity that correspond to specified percentiles of his subjective probability distribution. In most studies, the subjects state overly narrow confidence intervals which reflect more certainty than is justified by their knowledge about the assessed quantities. This bias is common to both naive and to sophisticated subjects, and it is not eliminated by introducing proper scoring rules, which provide incentives for external calibration. This effect is attributable, in part at least, to anchoring.

Interrogation Techniques

There are basically three interrogation approaches. Arranged in increasing order according to the time required for interrogation, these are:

workshops
interviews and questionnaires
Delphi

Workshop approaches to decision making are usually designed to attempt a consensus decision based on a collective examination of the issues. While each participant in the workshop may be a potential source of valuable information, the individual contributions are diluted and possibly suppressed.

First, the workshop environment permits the interaction of various egos and personalities, such that the results could be overly influenced by dominating or opinionated individuals.

Secondly, semantic noise frequently leads to a filtering and scrambling of information. This is primarily due to the difficulty in directing and focusing the group to the objective of the workshop, but even if effectively directed, there can be noise in communications among participants.

Finally, there always exists a group pressure for conformity that tends to suppress or minimize input from participants with different views or opinions.

The main advantage of a workshop approach is the speed with which decisions or opinions can be obtained.

Individual interviews and questionnaires require slightly more effort for the interrogator but provide the opportunity of higher quality results. The difficulty with this approach is that it does not easily permit reinterrogation after the interview or questionnaire response. Iterations might be valuable after the response from an entire group has been obtained. Another disadvantage is that the development of consistent interview procedures or the detailed elements of the questionnaire is very difficult.

The Delphi technique for quantification of expert opinion attempts to combine the best of the two previous approaches. A disadvantage of the Delphi technique is that it requires a great deal of effort on the part of the interrogator. The idea is for a group of experts to reach a consensual judgment slowly, independently, and anonymously. The format of the approach is very flexible and could involve either questionnaires or interviews. The key features are:

anonymity - eliminates the problems associated with group pressures and strong personalities

feedback - the interrogator, based on the results of a first round interrogation, formulates the questions for a second round, etc.

Synthesis Techniques

An expert is defined here to mean anyone with special knowledge about an uncertain quantity or event. The question of how to use such experts in the decision making process is one that has long plagued decision analysts.

Formal approaches to the expert use problem can usually be categorized as one of three types: 1) weighting schemes, 2) consensus methods, and 3) calibration approaches.

Weighting schemes normally involve combining expert probability assessments with subjective weights selected by the decision maker or whoever is evaluating the report. The difficulty with such methods is that they are ad hoc.

The consensus approach, typified by the Delphi method, aims to achieve some type of group consensus on an uncertain quantity. Two difficulties with this approach are that it offers no general rule for what to do if there is no consensus (typically, the approach taken in this case is some kind of weighting scheme), and it provides no rationale for why consensus should be the right answer.

In the calibration approach a subject is asked to provide probability assignments on many variables, from which his probability assessment performance is measured. Unfortunately, this approach deals with only one expert and appears contradictory when two calibrated experts disagree. Nevertheless, the concept of calibration is important in the study of how to use experts.

Application to WISAP

The ultimate decision regarding the application of subjective probability techniques to WISAP may be budget dependent. As was emphasized earlier, there is a wide variation in costs and benefits associated with each analysis technique, and these trade-offs will be carefully scrutinized during the scoping of the opinion collection phase.

Whichever interrogative mode is selected, the results will be of higher quality and obtained more readily if the participants have been briefed on the interrogation technique, and most importantly, on how to minimize the bias in their response. This briefing could be either in a workshop style, in a written introductory document, or a multi-media (e.g., tape recorder and slides) presentation. Whatever the presentation mode, such an introduction would be exceedingly cost-effective.

REPOSITORY MODELING PROGRAM AT LAWRENCE LIVERMORE LABORATORY (LLL) - Tom Holdsworth, Lawrence Livermore Laboratory

The Nuclear Regulatory Commission (NRC) has funded a program at LLL to evaluate the probability and consequences of breaching a high-level waste repository site. The program objective is to provide data for a framework for the NRC, who will write the regulations for a high-level waste repository. Even though the objectives of the NRC and the Office of Waste Isolation (OWI) programs are different, they are similar enough that problems and methodology can be interchanged. On this basis, Tom Holdsworth of LLL was invited to discuss aspects of their efforts that would be of value to the disruptive event analysis at Pacific Northwest Laboratory (PNL). Mr. Holdsworth qualified his presentation with the disclaimer that he was attending the workshop as a representative of LLL rather than of the NRC, and that any statements made reflected only his personal position and opinion.

One of the prime objectives of the effort at LLL is to provide data for site suitability regulations. Their strategy in modeling is to place a stress on multiple barriers, not on one particular phenomenon. The need is to analyze and ascertain the uncertainty or probability of breach, as well as the sensitivity of the environment to the breach. If the requirement is to reduce risk to the environment to a reasonable level, what is reasonable?

A data base must be used for the analysis that contains all aspects of the loss of repository integrity, the interaction of waste with the environment, and safe tolerance levels of the environment. As an example of one area of analysis, a breach of a repository by ground water was assumed at time zero. This necessitated the analytical identification and sensitivity of the relative system parameters such as model pathways and modifications due to permeability, fluid flow, formation or media interactions, and others. It is obvious that the criteria statements require a rigorous systems analysis structure.

The methodology for providing this rigorous system analysis is to make an exhaustive list of the characteristics involved. This list is then reduced to a manageable level so that the hierarchy of the model structures is also manageable. This means that the models must be keyed together in such a way that the entire model system is exercised fully. The parametric sensitivity analysis deals with both the multi-parameter variation cases and the uncertainty analysis. This process identifies the dominant parameter or parameters. The subroutines for these dominating parameters can then be removed and studied to provide additional details. This cycling can be repeated until acceptable levels of waste containment are reached. The LLL effort at the time of this workshop (July 1977) is at the stage of expanding and detailing the dominant parameters.

<u>WASTE DISPOSAL AND GEOLOGIC MEDIA INTERACTION MODELING PROGRAM AT SANDIA LABORATORIES</u> - Martin Tierney, Sandia Laboratories

The modeling program at Sandia is also funded by the NRC. The original intent of this program was to do a risk analysis of waste repository sites similar to studies of reactor safety, but this approach was abandoned due to the different interactions with the geologic media. Thus, the program assumed that a site would be known, such that release mechanisms and resulting media interactions could be determined.

The initial model chosen was a layered section based on the well-known hydrology and geology of Long Island. This section consists of a surface of glacial debris underlain by a thin shale, a sandstone aquifer, and finally a crystalline basement. A salt layer to contain the repository was inserted into the thick shale so that the repository would be approximately 600 m below the surface which was given a 1500-m elevation. The surface was exposed to 1 m of annual rainfall. Although this modeling was strictly an exercise, it was hoped the effort could be applied to southeastern New Mexico.

With this model, fault trees were used to obtain lists of factors that would influence the stability of the repositories. Some 75 items that initially were felt would affect the stability were reduced to 27 items, and these were again shrunk to 9 classes and labeled release modes. These release modes are:

1. self-induced release, including effects of excavation, and construction of the repository, the emplacement of the waste and resulting effects of the waste on the host rock
2. shaft failure
3. undiscovered bore holes
4. undiscovered voids and fractures
5. erosion and sedimentation effects
6. faulting
7. explosions - predominantly nuclear
8. magmatic intrusions
9. inadvertent intrusions.

Details of the model operation have been written up in an interim report to the NRC entitled "Development of Models for Examining Radioactive Waste Disposal," dated July 11, 1977.

EXPECTED CLIMATE STRESSES IN NORTH AMERICA IN THE NEXT ONE MILLION YEARS

- George Kukla, Lamont Doherty Geological Observatory

Obviously, with present knowledge, the prediction of future climate is not yet possible. However, an attempt can be made to estimate possible future extreme climatic stresses.

Two assumptions must be made: First, that the pattern of natural components of climatic variability during the next million years will approximately correspond to that of the past million years. Second, that the impact of man's future technology on the environment and climate will remain within reasonably foreseeable limits.

It is known that the world climate varies broadly on all time scales (U.S. CGARP 1975). In combination with tectonic and volcanic activity, the past changes of climate led to repeated profound transformations of the environment in North America, as well as in the rest of the globe.

It is also known that the periodicity of reconstructed gross climate changes during at least the last 0.4 million years closely correlates with the periodicity of the earth's orbital parameters (Milankovitch mechanism, Hays et al. 1976). It is widely agreed that a causal relationship links the two processes and that the dependence of climate on the earth's orbit will continue in the future (Flohn 1973, Kukla 1975, Mason 1976).

It is known that some short-term climatic phenomena, such as widespread droughts, positively correlate with the solar activity cycle, and it is expected that such correlations will also hold in the future (Mitchell 1977).

It is not known yet, however, how the climate system operates, and what the links are between the variation of orbital elements and climate, or between the solar activity and climate.

It is not known to what degree and in which way man interferes with natural climate-forming processes.

Basic considerations for a realistic definition of potential extreme climatic states and their duration and frequency (which is more important than their accurate timing) include the following:

technology - will man gain control over climate, have a negative interference, or retain the present technology level, which allows climate to progress in its natural way?

relief - climate is significantly affected by the distribution and morphology of continents and oceans, which can be expected to change in one million years

volcanic explosions - large or frequent volcanic explosions influence regional environments as well as global climate (Lamb 1969, Damon 1971)

timing - some climatic modelers propose that climatic variability may be entirely due to random processes (Lorenz 1968, 1976). However, most paleoclimatologists do recognize a quasi-periodic pattern in proxy records of climatic inductions. These records gathered over the past 0.5 to 1.0 million years follow the Milankovitch mechanism (Hays et al. 1976)

rates of climatic change - assuming that man's technology in the future does not include the ability to control the climate, the extreme stress processes and events recorded in the past million years will recur with approximately the same frequency and intensity.

PHYSICAL OCEANOGRAPHY: SEA LEVEL FLUCTUATIONS - Maurice Schwartz, Western Washington University

This discussion deals with available information and theories about sea level changes during the Cenozoic Era. This review uses the following breakdown:

1. 20 million years of late Tertiary
2. 2 million years of Quaternary (the Pleistocene)
3. 17 thousand years B.P. or the Flanderian Transgression
4. the last 100 years
5. the last 10 years.

The study of the past sea level record suggests a prediction of the future is possible. Extrapolation of possible climatic rate processes and glacial events can be examined through an extension of Milankovitch theory with the inclusion of additional variations on incoming solar radiation as calculated by Vernekar (1972) and by Berger (1976a, 1976b). The past record has indicated that sea level fluctuations are closely coupled to glacial periods and other climatic extremes.

Another feature having a major effect on climate changes, and hence, sea level fluctuations, is global plate tectonics. Perhaps of more importance, however, would be the stability of a particular continental coastal site. Elevation changes due to local tectonic uplift or subsidence could far outweigh world-wide tectonic or glacio-eustatic sea level changes. In addition, the effects of coastal erosion and sedimentation processes must be considered.

<u>PRELIMINARY CONSIDERATIONS OF THE EFFECT OF ICE AGE PROCESSES ON SITE SELECTION FOR NUCLEAR WASTE DISPOSAL SCHEMES</u> - Colin Bull, Ohio State University

The main effects of the glaciological processes and other disruptive events that would be associated with major changes in the quantity of ice on the earth can be divided into two classes:

1. those directly connected with the presence or disappearances of major ice sheets
2. those related to the major climatic changes associated with the changes in the ice sheets.

The following points among the direct effects deserve strong consideration in the selection of sites for nuclear waste disposal:

disappearance of currently existing ice sheets and the subsequent effects on sea level
reformation of ice sheets in North America
erosion
ground water
surface permeability
isostatic changes
permafrost and subsurface weathering
climatic changes associated with major changes in ice volume on the earth.

SALT DISSOLUTION/EROSION/SEDIMENTATION - Joseph W. Martinez, Louisiana State University

This presentation is primarily a discussion and review of the Office of Waste Isolation's Salt Studies Program being performed by the Institute of Environmental Studies at Louisiana State University, Baton Rouge. The progress of that program has been reported in annual reports (Martinez et al. 1975, 1976) and a symposium paper (Martinez and Thoms 1976). The discussion is best summarized by the following abstract.

Salt deposits have been recognized for a number of years as a particularly suitable rock type for the isolation of radioactive wastes. These deposits are common in sedimentary basins in the U.S. and elsewhere, and salt has physical properties which are advantageous for this purpose. Natural occurrences of rock salt are generally categorized morphologically as either bedded or dome types. Early studies of the potential use of salt for the isolation of radioactive wastes were focused on bedded salt. In the last several years attention has been directed to the possible utility of Gulf Coast salt domes for this purpose.

The toxicity of plutonium, a component of the waste, and its long decay period, 24,360 years half-life, requires special care in evaluating the degree of isolation provided by salt domes or other rock types. Feasibility studies have applied geologic, hydrologic and engineering disciplines to an assessment of the tectonic and hydrologic stability of Gulf Coast salt domes. These studies range in perspective from an evaluation of evidence provided by older geologic formations to current monitoring by various geophysical techniques.

The scientific studies coupled with an analysis of cultural setting have narrowed the possibilities from more than 400 domes in the Gulf Coast to a few promising study areas. So far, three areas have been selected for further study in both the North Louisiana Salt Dome Basin and the Northeast Texas Salt Dome Basin. New field work is expected to provide firmer conclusions regarding the suitability of these domes for radioactive waste isolation.

UPLIFT AND SUBSIDENCE OF GULF COAST SALT DOMES - Robert L. Thoms, Louisiana State University

The objective of this discussion is to present a summary of generally accepted concepts along with more speculative quantitative data involved with salt dome uplift. Possible problems and techniques for numerical modeling of salt dome tectonics are briefly noted. Subsidence of domes due to ground water dissolution is mentioned; however, quantitative data on dome subsidence have not been located in the literature and, in fact, may not exist.

The evolution of salt domes may be traced through three general stages (Atwater and Forman 1959, Kupfer 1970). As a bed of salt is progressively buried by ongoing sedimentation and basement sinking in time, the overlying sediments will compact to a greater density than the salt. This unstable system responds initially by formation of salt pillows. If dome evolution continues, the intermediate stage of growth includes formation of salt massifs which penetrate overlying sedimentary units (diapirism). The final stage of salt dome uplift is typified by approximately cylindrical salt stocks that stem upward from a broader base. Some domes in the final stage may be physically separated from the "mother" bed of salt.

A salt dome and surrounding geologic units may be considered as comprising a geomechanical system with behavior governed by active and passive forces. Buoyancy, furnished by density contrasts, drives the salt upward through overlying denser media. Passive forces influencing the system are determined by the relations of the system components. That is, material properties determine the passive characteristics of relative plasticity, strength, and frictional forces involved in the system at any particular point in time.

Subsidence of salt domes has occurred due to ground-water dissolution as evidenced by surface depressions existing, for example, over a number of inland basin Gulf Coast domes. Rates for site-specific cases have not been located in the literature. It appears that an upward flow of salt stock may replace salt transported away by ground water in many cases. The existence of cap rock over some relatively shallow domes which must have been exposed to dissolution implies some replenishment mechanism.

In summary, the general mechanics of salt dome evolution are well known; however, many specialized questions associated with salt dome uplift may still be posed. Rates of dome uplift have been estimated partially on the basis of plausible, but relatively arbitrary, assumptions. Additional site-specific data would yield a broader base for future estimates of dome uplift rates.

<u>SURFACE AND SUBSURFACE HYDROLOGY</u> - Warren Wood, U.S. Geological Survey

Hydrologic modelers face many of the same philosophical problems that face other modelers. In the field of hydrology there are two levels of uncertainty: 1) the inability to describe a hydrological system or aquifer as it really is and 2) the inability to describe completely the disruptive events and the probabilities of how a hydrologic system might change as a result. With respect to the first problem, we can make measurements on an existing aquifer in an attempt to improve the modeling and, hence, the predicting of how the system acts or reacts.

With the second problem there are essentially two areas that must be explored. One is the disruptive event itself and the probabilities that the given disruptive event will occur. Second is the question of how it will affect the system. Thus, the goal of the model is to determine a range of what the system can do or states the system will take.

The objective of the discussion at hand is the geologic isolation of high-level nuclear wastes, that is, the desire to keep waste or waste products out of the biosphere for acceptable lengths of time--in this case, probably one million years. This discussion predominantly addresses ground-water problems. This reasoning is based on the assumption that, if the repository has been breached by surface waters, a direct pathway to the biosphere has been created, such as a shaft-seal failure. In such a case the contaminants could then move directly into the biosphere. Therefore, the study should concentrate on subsurface hydrology and its possible interactions with the repository.

When looking at subsurface hydrology the properties of the media, such as the fluid, the flux or flow rate, the porosity, and the permeability must first be addressed. The porosity of a subsurface formation can range from less than 1% for a limestone or igneous rock, to 30-35% for sandstones, and around 50% for clays. Intrinsic permeability may range from 10^5 cm^2 to 10^{-8} cm^2. These factors are related through Darcy's equation for fluid flow.

$$Q = KA(h_1-h_2)/dL = KA\ dh/dL \qquad (1)$$

where Q is the flux or flow rate in cm^3, A is the cross-sectional area in cm^2, h is the head in cm, L is the flow path length in cm, and K is the fluid conductivity. The conductivity can be defined as $K = k\frac{\gamma}{\mu}$, where γ is the specific gravity of the fluid, μ is the dynamic viscosity of the fluid, and k is the permeability of the medium. The permeability of the medium can in turn be described by $k = cd^2$, where d is a characteristic length, such as the average pore size of the aquifer, and c is a dimensionless constant or shape factor which takes into account the effects of stratification, packing, arrangement of grains, size distribution, and porosity. The viscosity is temperature dependent; a temperature increase from 0 to 50°C approximately halves the viscosity. Density, or specific gravity, may range from 1 to 3 for the ground water or fluid.

How do these factors affect the flux flow or recharge, Q? If there is a doubling of rainfall on the surface, it is obvious that Q is not doubled. Equation 1 shows that all factors remain constant, so a doubling of rainfall does not necessarily double the flow rate. Q is a direct function of the gradient dh/dL, so increasing the gradient could increase Q. If there is a drop in sea level of 150 m, the gradient may go from 20 cm/km to 40 cm/km. A more effective way to increase the recharge or flow rate of an area would be to increase K. Changes on the order of 12 or 13 orders of magnitude are possible, depending on the permeability.

Finally, dispersivity must be considered. Dispersivity is a mixing phenomenon dealing with a combination of molecular and hydrodynamic diffusion. Dispersivity is also called the "characteristic length" in modeling terminology and varies in the field from 0.1 m to 150 m. The major effects of dispersivity is in the transport of the undesirable nuclei.

We should now look at some of the problems associated with the waste repository site. The major problem is obtaining data on the permeability and porosity of the media containing the repository and of the adjacent media. These data are necessary to model the repository site and, hence, the interactions that might take place with respect to ground water breaching the repository. Climatic changes are also important because the effects caused by these changes may increase the recharge or change the permeabilities. The ground-water hydrology, in itself, may be a problem, and, in this case, modeling should be site specific. Erosion is a third problem area because it can change the ground-water recharge and discharge points, as well as the gradient by removing impermeable beds. Fracturing is a problem which makes hydrologic modeling difficult. It is impossible to avoid fracturing near or around the repository site when it is being excavated. Prediction of ground-water flow is another problem area; in granular media, such as sands, gravel, silts, it is not too difficult to determine the fluid flow. There is a history of success in this area, and there is confidence in the modeling. An area of poor success is the prediction of water in mines, tunnels and other similar underground excavations. The problem, in the latter case, is associated with nongranular materials, such as shales and granite, both of which are subject to fracturing.

In reviewing the needs of a safe repository site one finds a critical need for the following attributes in the surrounding geologic media: low permeability, high porosity, a low hydrologic gradient, high absorptive capacity of the immediately surrounding media such as shales or bentonite, a long flow path, and a closed hydrologic system (or one with downward flow only). Also, the waste should be cool and in an insoluble form. There is also a need for additional research into the development of two-phase flow, which results when the ground water is heated enough by the waste to produce steam and water.

VOLCANISM AND IGNEOUS INTRUSIONS - Bruce Crowe, Los Alamos Scientific Laboratory

Risk analysis of hazards due to igneous activity has long been and is currently a major concern to society. Historic eruptions, particularly of volcanoes near populated areas, are a major hazard to both life and property. For example, the 1902 eruption of Mount Pelee, an active volcano located on the island of Martinique in the Lesser Antilles, destroyed the city of St. Pierre and killed thousands of people. The recent increase in steam activity from Mt. Baker in northern Washington led to the closure of recreational areas on the east slope of the cone.

Surveillance techniques that give scientific credibility to volcanic predictions have been established only in the last decade. Current efforts are directed toward several general areas:

1. Surveillance and prediction of renewed or increased levels of activity at dormant or active cones. Short-term prediction and assessment of risk probabilities from life-endangering eruptions.
2. Volcanic hazards or volcanic zoning. Assessment of high risk zones from volcanic processes (for example, air fall, pyroclastic flow, mud flow) on, and adjacent to, active volcanoes.
2. Nuclear reactor siting. Evaluation of the potential risk to a reactor installation from volcanic activity.

These prediction problems are short term in that they are directed toward prediction of volcanic activity on a time scale of months or, at most, years. The risk analysis of a disruption of a radioactive waste repository site from igneous activity expands the time scale to as great as one million years. During the last million years, major areas of the western United States were sites of significant volcanic activity. High risk areas from future volcanic activity need to be predicted and the scope of hazards for each area identified.

The "worst case" disruptive event to be considered is that of volcanic activity directly intersecting the repository site. Some factors which will control the pathway and dispersal distance of incorporated radioactive waste during disruption of a repository site by volcanic activity include:

composition of the volcanic activity
intersection of the repository by a volcanic conduit
dispersal mechanisms controlled by topography and aerial activity.

A scenario with a higher probability of occurrence than onsite volcanism is the occurrence of activity away from the repository site but close enough for secondary effects, including surficial mantling by volcanic ejecta, vegetation and drainage modifications, and climatic effects.

Another scenario with dominant secondary effects is that of an igneous intrusion rising to some unspecified depth below a repository but not actually intersecting the repository. Some of the potentially disruptive secondary effects include:

broad dome uplift and development of a fracture system, with accelerated erosion rates
juxtaposition of a hydrothermal convection system above the magma chamber
upward propagation and eruption of surface volcanism fed from the intrusion.

There are some ongoing problems which include volcanic hazard analyses and model predictions. Data from these may be reinterpreted and extended, so a waste repository site can be selected to minimize risk from volcanic activity. Hence, broad areas can be identified as high risk areas for volcanic activity in the next million years.

SEISMOLOGY AND WISAP - Larry Wight[a]

The objective of this report is to define the framework of a model that relates the occurrence of future earthquakes probabilistically and further characterizes the effects of these earthquakes on the underground radioactive waste repositories. The time scale of the problem is approximately one million years, and the effects that must be quantified are those that would provide pathways for the transport of radionuclides. The scope of the problem is clearly such that the only suitable approach is probabilistic.

There is, of course, the possibility that man in the next million years could develop techniques that permit modification or control of earthquakes. Consistent with the overall conservative policy of WISAP, this corresponding reduction in risk is not considered, although the probability of this technology becoming available is very high. There is one scenario, incidentally, by which the advanced technology might actually increase the risk at a repository. If the site were situated in an aseismic area, future man's modification of activity might significantly increase the seismicity (and, therefore, risk) in the site vicinity. Assessing this problem is very difficult, and quantification of future technology is impossible.

Thus, the seismology study should include:

1. the relevant effects of earthquakes on a repository
2. conceptual methods available for their prediction
3. application and extension of conventional seismic risk calculations to WISAP.

(a) Dr. Gerald Frazier, formerly of the University of California at San Diego and presently of Del Mar Technical Associates, Del Mar, California, was scheduled to present the discussion on seismology but was unable to attend the workshop. L. H. Wight, who had worked with Dr. Frazier, graciously filled in for him.

LONG-TERM METEORITE HAZARDS TO BURIED NUCLEAR WASTE MATERIAL -
William K. Hartmann, Planetary Science Institute

For those who dismiss the meteorite impact hazard to buried nuclear wastes, a few facts might cause a re-thinking of the problem. At least one meteorite impact occurred in this century with an energy comparable to a nuclear weapon of several hundred-kiloton-yield (Siberia in 1908). In recent decades, people and property have been struck by meteorites, albeit small stones that had been slowed to low terminal velocity in the atmosphere. In old regions of the earth, which have recorded impacts for hundreds of millions of years, large meteorite craters (in eroded, degraded form) have been found with diameters at least 60 km and original depths of several kilometers. Thus, if a nuclear industry proliferates and produces widely scattered waste deposits with dangerous lifetimes of centuries, the question of unpredictable explosive excavation by meteorites becomes one that should be examined.

This study is limited to the rate of excavation of the earth's surface by meteorite impact (with two independent methods being used to estimate the rate). The first method (called terrestrial-theoretical) relies on measures of the rate of infall of meteorites of different masses, measured directly on earth and by lunar surface measures. These are then converted by formulae into impact craters of various diameters and depths, which are then used to estimate the time required to excavate any given percentage of an exposed surface. The second method (lunar-empirical) invokes direct observations of the percentage of areas on the moon excavated to different depths, on surfaces of known age. The rates of excavation computed by the two methods agree within a factor of about five.

Since the impacts are distributed nearly at random, timescales become proportionately reduced as the number of sites proliferates. This raises the question of evaluating not only the failure probability for a single site, but the potential for proliferation of nuclear waste sites, once an expanding nuclear power industry is introduced into a society where it may grow over a period of decades or centuries.

During a million-year period for a repository buried at 600 m depth, as considered at this workshop, the probability of breach by fractures under an impact crater appears to be of the order 10^{-5}, and the probability of complete excavation by impact appears closer to 10^{-6}.

NON-SALT AREAS - Fred Donath, University of Illinois

Some results of a program performed by the American Physical Society Study Group on Nuclear Fuel Cycles and Waste Management and funded by the National Science Foundation are presented. This study group felt it necessary to call attention to the important medium of radionuclide transport for buried radioactive waste. The transport which is capable of potential transfer of radionuclides from repository to the biosphere is ground water. It is possible that a favorable ground-water regime could, by itself, provide effective waste isolation. In such a case, the ground water would have to migrate slowly enough so that the radionuclides would not reach the biosphere during the desired period of isolation. Because of the extreme importance of hydrology to high-level waste management, the parameters that characterize the hydrogeologic system and an appropriate means of quantitatively analyzing the ground-water regime were discussed. The results of this study group were reported to the American Physical Society in July 1977 and published in January 1978 (Hebel 1978).

REFERENCES

Atwater, G. I. and M. H. Forman. 1959. "Nature and Group of Southern Louisiana Salt Domes and Its Effect on Petroleum Accumulation; Amer. Assoc. Petrol. Geol. Bull. 33:2592-2622.

Berger, A. L. 1976a. "Long-term Variations of the Earth's Orbital Elements," in Abstracts of Forthcoming Articles: Celestial Mechanics. 13:523.

Berger, A. L. 1976b. "Obliquity and Precession for the Last 500,000 Years," Astronomy and Astrophysics. 51:128-135.

Damon, P. E. 1971. "The Relatioship Between Late Cenozoic Volcanism and Tectonism and Orogenic-Epeirogenic Periodicity," The Late Cenozoic Glacial Ages. K. K. Turekion, ed. Yale University Press, p. 15-35.

Dayem, N. L., T. Holdsworth, D. Towse, D. Isherwood and R. Heckman. 1977. Site Suitability Criteria for Solidified High Level Waste Repository. Lawrence Livermore Laboratory, Preliminary Draft to NRC.

Flohn, H. 1973. "Naturliche and Anthropogene Klimamodifikationen," Sonderabdruck aus Annulen der Meteorologie. Neue Folge, (6):55-66.

Hays, J. D., J. Imbrie and N. G. Shackleton. 1976. "Variations in the Earth's Orbit: Pacemaker of the Ice-age," Science. 194:1121-1132.

Hebel, L. C., Chairman. 1978. "APS Study Group on Nuclear Fuel Cycles and Waste Management," Reviews of Modern Physics. 50(1) Part II:51-S196.

Kukla, G. J. 1975. "Loess Stratigraphy of Central Europe," After The Australopithecines. K. W. Butzer and G. L. Isaac, Ess., Mouton Publishers, Paris, p. 99-188.

Kupfer, D. H. 1970. "Mechanism of Intrusion of Gulf Coast Salt," The Geology and Technology of Gulf Coast Salt. Kupfer, D. H., Ed., School of Geoscience, Louisiana State University, p. 25-66.

Lamb, H. H. 1969. "Volcanic Activity and Climate," Palaeogeography, Palaeoclimotol., Palaeoecol. 10(2/3):203-230.

Lorenz, E. N. 1968. "Climatic Determinism," Meteor. Monogr. 8(30):1-3.

Lorenz, E. N. 1976. "Nondeterministic Theories of Climatic Change," Quat. Res. 6:495-506.

Martinez, J. D., D. H. Kupfer, R. L. Thoms, C. G. Smith, C. R. Kolb. 1975. An Investigation of the Utility of Gulf Coast Salt Domes for the Storage or Disposal of Radioactive Wastes. Report No. ORNL-Sub-4112-10, Institute for Environmental Studies, Louisiana State University, Baton Rouge, LA, 204 pp.

Martinez, J. D., R. L. Thoms, D. H. Kupfer, C. G. Smith, C. R. Kolb, E. J. Newchurch, R. E. Wilcox, T. A. Manning, M. Romberg, A. J. Lewis and J. E. Rovik. 1976. An Investigation of the Utility of Gulf Coast Salt Domes for the Storage or Disposal of Radioactive Wastes. Report No. ORNL-Sub-4112-14. Institute for Environmental Studies, Louisiana State University, Baton Rouge, Louisiana, 329 pp.

Martinez, J. D. and R. L. Thoms (ed). 1976. Proceedings of a Symposium on Salt Dome Utilization and Environmental Considerations. Held at Louisiana State University, November 22-24.

Mason, B. J. 1976. "The Nature and Prediction of Climatic Changes." Endeavor. XXXV:5157.

Mitchell, M. J. Jr. 1977. "Drought Cycles in the United States and Their Relation to Sunspot Cycles Since 1700 A.D.," EOS Trans Agu. 58(8):694.

Raymond, J. R. 1978. Workshop on Transport Modeling for the Safety Assessment Program on Nuclear Waste Isolation. PNL-2707, Pacific Northwest Laboratory.

U.S. Committee for the Global Atmospheric Research Program. 1975. Understanding Climatic Change: A Program for Action. National Academy of Sciences.

Vernekar, A. D. 1972. "Long-period Global Variations of Incoming Solar Radiation," Meteorological Monograms. 34. American Meteorological Society, Boston.

APPENDIX

LIST OF ATTENDEES FOR WORKSHOP ON POTENTIALLY DISRUPTIVE PHENOMENA FOR NUCLEAR WASTE REPOSITORIES, BATTELLE SEATTLE RESEARCH CENTER JULY 27 AND 28, 1977

APPENDIX

LIST OF ATTENDEES FOR WORKSHOP ON POTENTIALLY DISRUPTIVE PHENOMENA FOR NUCLEAR WASTE REPOSITORIES, BATTELLE SEATTLE RESEARCH CENTER JULY 27 AND 28, 1977

George E. Barr
Div. 1141
Sandia Laboratories
P.O. Box 5800
Albuquerque, NM 87115

Colin B. B. Bull
College of Math > Physical
  Sciences
Ohio State University
Columbus, OH 43210

Harry C. Burkholder
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

H. C. Claiborne
Office of Waste Isolation
Union Carbide Corporation
  Nuclear Division
Oak Ridge, TN 37830

Bruce M. Crowe
Geological Research Group
Mail Stop 978
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

Les R. Dole
Office of Waste Isolation
Union Carbide Corporation
  Nuclear Division
Oak Ridge, TN 37830

Fred A. Donath
University of Illinois
Department of Geology
Urbana, IL 61801

Jay R. Eliason
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Ian Forbes
Energy Research Group, Inc.
1661 Worcester Road
Framingham, MA 01701

Jess Greenborg
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

William K. Hartmann
Planetary Science Institute
2030 E. Speedway
Tucson, AZ 85719

Tom Holdsworth
Lawrence Livermore Laboratory
Mail Stop L 156
Box 808
Livermore, CA 94550

Jimmy J. Jacobson
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Konrad B. Krauskopf
Stanford University
Stanford, CA 94305

George J. Kukla
Lamont Geological Observatory
Palisades, NY 10964

Joseph D. Martinez
Institute for Environmental Studies
Room 42 Atkinson Hall
Louisiana State University
Baton Rouge, LA 70803

William C. McClain
Office of Waste Isolation
Union Carbide Corporation
Nuclear Division
Box Y
Oak Ridge, TN 37830

Herbert M. Parker
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Peter J. Pelto
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Maurice Schwartz
Dept. of Geology
Western Washington University
Bellingham, WA 98225

James A. Stottlemyre
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Robert L. Thoms
Institute for Environmental Studies
Louisiana State University
Baton Rouge, LA 70803

Martin Tierney
Sandia Laboratories
Div. 5413
Albuquerque, NM 87115

James W. Voss
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Richard W. Wallace
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

Larry H. Wight
TERA Corporation
2150 Shattuck Ave.
Berkeley, CA 94703

Warren W. Wood
U.S. Geological Survey
Mail Stop 410
Reston, VA 22092