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WORKSHOP ON GEOLOGIC DATA REQUIREMENTS
FOR RADIOACTIVE WASTE MANAGEMENT ASSESSMENT MODELS

Workshop Chairman:
Stanley E. Logan

This informal document contains information which is preliminary and may be fragmentary or of limited scope. The assumptions, views, and conclusions expressed in this document are those of the author and are not to be interpreted as those of Union Carbide Corporation, Nuclear Division, or USERDA.

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September 1976

*Prepared for Office of Waste Isolation
Union Carbide Corporation, Nuclear Division
under its contract with the
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Development Administration*

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FOR RADIOACTIVE WASTE MANAGEMENT ASSESSMENT MODELS**

Santa Fe, New Mexico

June 28 - July 1, 1976

Workshop Chairman:
Stanley E. Logan

September 1976

Prepared for

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Union Carbide Corporation, Nuclear Division
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ACKNOWLEDGEMENTS

The suggestion to hold this workshop originated with William McClain of the Office of Waste Isolation. The University of New Mexico appreciates being invited by OWI to do the planning and make the arrangements.

Assisting with the planning, arrangements, and conduct of the workshop were Professor Mario Berbano of the Chemical and Nuclear Engineering Department, and graduate students: Robert Erickson and Carl Herrmann.

H. Clyde Claiborne of the Office of Waste Isolation acted as liaison between OWI and UNM and was most helpful in many ways.

Interpretative notes were taken during the workshop by my wife and supper hour geology consultant: Marjorie Logan. A geology degree (UNM, 1970) and familiarity with the UNM assessment model helped to bridge the jargon of the two groups attending the workshop. The many hours spent since the meeting reviewing tape recordings completed the summary notes from which this report was prepared; this effort is appreciated.

Last but not least, the contributions by the almost 75 persons attending the workshop are acknowledged. This includes those who provided presentations on background topics and the entire group for incisive questions and comments. The success of the workshop is due to the enthusiastic and animated dialogue which occurred. Particular appreciation is expressed to attendees who traveled from foreign countries to participate: Robert Lyon from Canada, Jan Hamstra from the Netherlands, Ferruccio Gera from Italy, and David Gray from England.

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ABSTRACT

Exchange of information is needed among persons working in two broad categories of studies concerned with terminal storage of radioactive waste. These two categories are: 1) investigations of several types of geologic formations in a number of locations to determine suitability for use with various emplacement techniques, and 2) development of models for the ERDA, NRC, and EPA, for the general purpose of assessing the long term safety of terminal storage facilities. The Workshop held in Santa Fe, New Mexico, June 28-July 1, 1976, sponsored by the Office of Waste Isolation and arranged by The University of New Mexico addressed this need. Presentations covered background topics of: geologic studies being made, methods for risk analysis, assessment models being developed, and descriptions of field observations of radionuclide migration. During vigorous discussion periods, a list of items to be jointly attacked by geologists and modelers was worked out.

INTRODUCTION

A national program (National Waste Terminal Storage Program) is underway to provide federal repositories at multiple geographic locations with differing geologic formations for terminal storage of high level commercial radioactive waste. The total effort involves several federal agencies, government agencies, universities, and private organizations. A need has developed for exchange of information among persons working in two broad categories of studies concerned with terminal storage of waste. The two categories are: 1) investigations of several types of geologic formations in a number of locations to determine suitability for use with various emplacement techniques, and 2) development of models for the ERDA, NRC, and EPA, for the general purpose of assessing the long term safety of terminal storage of waste.

Union Carbide Corporation, Nuclear Division's Office of Waste Isolation (OWI) has been given the responsibility by the Energy Research and Development Administration (ERDA) to establish several pilot plants leading to waste repositories in geologic structures, along with the management, technical direction, and coordination of all aspects leading to that objective. The sequence of this work is planned as follows:

- 1) Identification of formations of interest, 2) Reconnaissance surveys,
- 3) In situ tests, 4) Area studies, 5) Detailed confirmation studies,
- 6) Establishment of a pilot plant, 7) Expanded pilot plant operations,
- and 8) Conversion of the pilot plant into a federal repository. The preliminary schedule calls for the first two pilot plants to begin operation in 1985 with others following at two year intervals.

The practice today is to subject nuclear facilities of any type to a very thorough and rigorous risk analysis. This is certainly expected to be the case for geologic terminal storage facilities. The OWI is not developing technology assessment methodology, but their staff will interface with other organizations who are doing this work and apply these techniques as required. The OWI observed a need to bring the geologic studies group and the assessment model developers together in a workshop for an exchange of information and contracted with The University of New Mexico for this purpose.

The objectives for the workshop are as follows:

1. Office of Waste Isolation: Provide a more complete understanding of requirements of models. This permits structuring of geologic studies to obtain data needed for the models while other geologic work is being done rather than having to go back to the field as an afterthought. A feel for types of data required by the modeler to carry out the analysis is needed.
2. Geologists: Provide an understanding of how models are being developed, what they do and don't do, and what their overall strengths and limitations are.
3. Modelers: Provide a better understanding of the problems faced by geologists in supplying data needed for the models. Geology is not easily reduced to numerical probabilistic forms.
4. Discussion: Explore the interface between the two groups, representing a broad range of backgrounds, and define common goals instead of dissolving into two isolated esoteric discussions.

The workshop attendees represent many of the institutions, organizations, and individuals actively working in the subject area. The purpose was to bring together a diversity of viewpoints with a relatively small group in order to attain the workshop objectives. It is recognized that there are many other persons with a strong interest in the subjects covered; it is hoped that this report will assist in spreading the scope of dialogue initiated at the workshop.

The first part of the agenda (in the next report section) covered background topics: geologic studies being made, methods for risk assessment, assessment models being developed, and descriptions of field observations of radionuclide migration. The latter part of the agenda was give-and-take discussion which worked out a list of items to be jointly attacked by geologists and modelers. The technical presentations provided a cross section of work in progress and certainly did not include all work being done. This report contains a brief summary of each presentation, to serve as a guide to the topics covered. The points brought out during the discussion periods are then reviewed.

WORKSHOP AGENDA

Tuesday, June 29, 1976

SESSION 1. Moderator: S. E. Logan, The University of New Mexico
9:00 - 9:15 Welcome and Introductions. S. E. Logan, Workshop Chairman
9:15 - 9:45 Purpose, Scope, and Objectives of Workshop.
W. C. McClain, Office of Waste Isolation
9:45 - 10:45 Summary of Geologic Studies and Implication to Risk
Assessments. T. F. Lomenick, Office of Waste Isolation
10:45 - 11:05 Coffee Break
11:05 - 11:50 Introduction to Risk Assessment. J. B. Fussell,
University of Tennessee
12:00 Lunch

SESSION 2. Moderator: H. C. Claiborne, Office of Waste Isolation
1:40 - 2:35 ERDA Assessment Model. H. C. Burkholder, Battelle
Pacific Northwest Laboratories
2:35 - 3:30 EPA Assessment Model. S. E. Logan, The University of New
Mexico
3:30 - 3:50 Coffee Break
3:50 - 4:45 NRC Model. P. E. McGrath, M. Tierney, Sandia Laboratories
4:45 - 5:00 Assessment Models for Shallow-Land Burial Site Operations.
G. L. Meyer, Environmental Protection Agency,
J. F. Davis, New York State Geological Survey

Wednesday, June 30, 1976

SESSION 3. Moderator: H. C. Burkholder, Battelle Pacific Northwest
Laboratories
8:45 - 9:25 Introduction to Geosphere Transport of Disposed Radio-
active Waste: The Associated Assessment Modeling Prob-
lems. C. R. Cole, R. J. Serne, Battelle Pacific Northwest
Laboratories
9:25 - 10:10 Migration at the Hanford Site.
R. A. Dejur, Atlantic Richfield Hanford Co.,
C. R. Cole, R. J. Serne
10:10 - 10:30 Coffee Break
10:30 - 11:00 Migration from Burial Grounds. M. L. Wheeler,
Los Alamos Scientific Laboratory
11:00 - 11:15 Migration in the Lithosphere. A. M. Friedman, Argonne
National Laboratory
11:15 - 12:00 Migration at the Nevada Test Site. L. D. Ramspott,
Lawrence Laboratory at Livermore
12:00 Lunch

SESSION 4.

- 1:45 - 2:30 Geochemical Aspects of Oklo. E. A. Bryant, Los Alamos Scientific Laboratory
- 2:30 - 5:30 Discussion Period.
Discussion Leaders: H. C. Burkholder, S. E. Logan,
P. E. McGrath

Thursday, July 1, 1976

- SESSION 5. Moderator: W. S. Twenhofel, U. S. Geological Survey
- 9:00 - 9:15 Interpretative Summary of Oklo. D. G. Brookins,
The University of New Mexico
- 9:15 - 11:00 Discussion Period.
- 11:00 - 11:15 Concluding Remarks. W. C. McClain

SUMMARY OF TECHNICAL PRESENTATIONS

Summary of Geologic Studies and Implication to Risk Assessments, T. F. Lomenick, Office of Waste Isolation.

The Office of Waste Isolation (OWI) charge by ERDA includes the responsibility of identifying rocks and formations suitable for radioactive waste repositories. Identification of formations of interest involves a study of all physiographic provinces. The formations divide generally into three types: salt (bedded salt and salt domes), shale deposits (including shales, mudstones and claystones), and crystalline rocks. The formations being studied touch almost every state in the United States. The emphasis is on selection of sites which can provide complete containment of waste for a period of 250,000 years.

The two possible causes of disruption of a repository can be divided into two classes. One is natural events which can result in penetrating the repository or surrounding area: faulting, meteorite strikes, and other slow, geologic processes. The other is a group of man-made events: subsidence through collapse of overburden, seepage into bore holes and shafts, effects of hydrofracture, etc.

Introduction to Risk Assessment, J. B. Fussell, University of Tennessee.

Risk is defined as the product of the probability of the occurrence of an event and the cost or consequences of an occurrence. Studies of natural and man-made systems show that the greater the consequences of an event, the less probable it is to happen. Risk is then reduced by either reducing the consequences of an event or reducing the possibility for occurrence.

A log-log plot of probability versus consequence, Fig. 1, is the representation by Farmer. For a given set of conditions, there is some iso-risk line which divides risk into acceptable and unacceptable risks to society.

Analysis divides into: 1) deterministic, where everything is determined by a sequence of actions independent of one's will, and 2) stochastic, where events are random and determined by probabilities. The latter

Figure 1. Farmer curve

is handy for "grey areas" and is used for risk assessment. Geologists are deterministic in their approach.

The light water reactor safety study (WASH-1400) used a stochastic approach and the method is gaining public domain and federal agency acceptance. It is suggested that the method should be extended into waste management risk assessment.

ERDA Assessment Models, H. C. Burkholder, Battelle Pacific Northwest Laboratories.

The objective of nuclear waste management is to sufficiently isolate the waste so that risks to present and future man are within acceptable limits. Risk to man is determined by the probability or chance of radioactivity release. The most likely release pathway between the geologic isolation site and man's environment is dissolution and transport of the waste by flowing groundwater. Consequence evaluation involves modeling the steps of the release and transport process: 1) invasion of site by water and failure of containment, 2) dissolution or leaching of waste, 3) transport of nuclides through geologic medium to the biosphere, 4) transport through biosphere to man, and 5) interaction of nuclides with man. Geologic isolation provides barriers to the first three steps: stable formation, low leach rate waste form, and reduction of nuclide migration by sorption processes.

A geosphere transport model has been developed which describes the transport processes of the third barrier (nuclide retention), given a failure of the first two barriers (waste form and formation integrity). Boundary conditions provide for either an impulse release or a band release (release over a band of time). Release rate depends upon the leach rate used. This, in turn, depends upon the chemical characteristics of the waste form, groundwater acidity, and temperature. Once in groundwater, sorption of the isotopes of a particular element is related to a distribution coefficient, designated as K_d for particular media and K_a for faulted monolithic media. Sorption is affected by groundwater acidity, concentrations of dissolved salts and dissolved nuclides, and solution temperature.

The groundwater transport model assumes a constant water velocity from the repository through a one-dimensional column of the medium and discharge into a surface water body. The decay of nuclides (including chain decay of the actinides) is modeled both in the repository and in the geologic medium. Because the degree of sorption varies for the nuclides, and hence the degree of flow retardation, the discharge at the surface water body is separated into relatively sharp chromatographic peaks as shown by the sample in Fig. 2.

Figure 2. Portion of simplified chromatogram for typical nuclide discharge to the biosphere.

The release consequences are calculated as a function of three parameters called waste management control variables. The time that water first contacts the waste (initial release time) is a measure of canister integrity and site stability from water protection. The time for complete dissolution of the waste (leach time) is a measure of waste form leach resistance. The distance that the dissolved nuclides move through the geologic medium to the biosphere is a measure of geosphere isolation. The surface generated by a three-dimensional plot for an assumed incremental dose level, for combinations of path length, leach time, and time of initial release is referred to as a waste management control surface. In Fig. 3, if the control surface is plotted for a reference dose, any point above the surface is a lower dose and any point below the surface represents a combination of parameters giving a higher dose.

Figure 3. Waste management control surface for incremental background dose.

The geosphere transport model requires sorption data for the geologic medium under investigation. To date, all sorption measurements have been made using surface or near-surface soils and rocks, and no sorption measurements have been made using deep geologic media. The general applicability of surface and near-surface sorption data to deep geologic disposal has not been assessed. Sorption measurements to date have almost

exclusively been made in the laboratory. However, in the future it may be practical or necessary to augment or replace the laboratory measurements by in situ measurements at the waste isolation sites.

EPA Assessment Model, S. E. Logan, The University of New Mexico

The Radioactive Waste Management Systems Model has several parallel paths, each representing a phase in the waste management sequence: residuals treatment (interim surface storage, solidification, etc.), waste transport, repository operations, and terminal storage. Implementation of the model is by the AMRAW computer code (Assessment Method for Radioactive Waste Management). The code runs calculations separately for each branch of the model and accumulates economic damages charges for each branch which is implemented. The current effort is applied to the terminal storage (disposal) branch. This will be followed in later work by implementation of the repository operations branch and in turn the waste transport and residuals treatment (at the fuel reprocessing plant) branches.

Each branch of the model (Fig. 4) is entered with the mass of each significant radionuclide in the inventory at risk. This is converted to curies in the inventory by an activity transfer coefficient (specific activity). The Fault Tree Model or equivalent logic model evaluates the probability for release by each of numerous potential release mechanisms, and the fraction of the inventory released by each such occurrence, during each increment of time. AMRAW may be run with three different fault tree modes: 1) probabilistic mode in which the fractional annual release from each event is equal to annual probability of occurrence times fraction released per occurrence, 2) one or more release events assumed to occur during a specified time interval, or 3) potential release events each occurring at a mean time as determined by separate statistical analysis. The second of these modes represents the "what if" mode and evaluates consequences of events without requiring use of an estimated probability.

Releases as determined by fault tree analysis are not necessarily directly to the environment. This is particularly true for deep releases to ground water. The first portion of the Environmental Model is therefore the "Transport to Environment" section. This adjusts each release increment, obtaining the contribution-to-concentrations in environmental input receptors at various times following release. These receptors

Figure 4. One branch of systems model.

are: air, ground surface, surface water, and ground water. The adjustment provides for dispersion into each of several geographical zones comprising the region around a repository, and then accounts for dispersion areas or volumes in each zone. The adjustment also accounts for decay from the time of release to the time being evaluated, transfer between receptors (such as deposition from air onto ground and resuspension into air), retardation in ground water flow, and other environmental removal or fixation processes.

The last portion of the environmental model covers the pathways from environmental input concentrations to radiation dose to man, with dose rate calculations for several organs of concern. Pathways include immersion in

air, inhalation, ingestion of ground water and contaminated food and drink (from contaminated ground surface and surface water), submersion in water, and direct surface exposure.

The Economic Model applies incidence rates of health effects associated with radiation dose to whole body and critical organs, and calculates the economic costs of health effects in the population. These costs are determined for each radionuclide considered, some of which are daughter products. The costs are then collected by decay groups and allocated to the appropriate precursor elements initially present in the waste. The allocated costs provide a common reference base for summing up the consequences of a number of health effects associated with many different radionuclides, with consideration of the population affected, agricultural activities, and other factors. Feedback of these calculated costs to the fuel reprocessing and residuals treatment phase provides a basis for comparison of reprocessing and waste partitioning options.

The AMRAW Code is structured with sequences of "receptors" separated by transfer coefficients, as illustrated in simplified form in Fig. 5. The receptors, shown as hexagons, represent the progress of releases,

Figure 5. Simplified representation of sequence in AMRAW Computer Code.

environmental concentrations, concentrations in food and drink, radiation doses, health effects and associated economic damages. The transfer coefficients, shown as circles, are evaluated in subroutines using externally

determined input data. The subroutines can be readily modified or replaced, providing a modular arrangement. Factors for dispersion, biological accumulation, dose, etc., used in the transfer coefficients, are evaluated by various existing transport and dose codes developed at ORNL, BNWL, and elsewhere. The entire sequence shown in Fig. 5 and various portions of it are repeated many times to accumulate the various parallel contributions at each step from various release events, transport modes, pathways, categories of dose, and for each nuclide of interest. Ground water transfer coefficients are evaluated within AMRAW. Geologic input required includes: 1) consultation to define a fault tree diagram or equivalent logic model which represents possible disruptive events at a specific site, 2) estimation of probabilities and possible extent of each type of event, 3) hydrologic data to determine response to faulting and ground water transport, and 4) interaction for interpretation of results. A preliminary list of geologic data requirements and associated questions uncovered during this study was distributed for discussion. In summary, the methodology and computer code serves as a vehicle for bringing together data from several disciplines in an organized manner.

NRC Risk Methodology, P. E. McGrath, M. Tierney, Sandia Laboratories.
(Other contributors for material presented were J. P. Brannen, J. E. Campbell, D. D. Carlson, and R. T. Dillon).

Development of a risk methodology for the evaluation of radioactive waste disposal by the NRC has been started. Objectives are to develop repository criteria and to assure long-term safety for licensing purposes.

Boundary conditions of the work are:

1. The methodology must describe the waste disposal facility in a manner adaptive to NRC's view of waste management.
2. The waste disposal facility is to be described forward in time from the point it is decommissioned.
3. Versatility to describe different geologic concepts and sites must be maintained.
4. The analysis is not to be a "worst case" analysis or a single point estimate; it is to be based on a risk evaluation. In a risk evaluation, the full spectrum of consequences is shown with the assigned probabilities of occurrence, and the estimated uncertainty in results.

Some of the outputs from a risk evaluation are: 1) radiological health effects on man, 2) resource denial, and 3) resource commitment for correction of an error in the facility.

The general flow chart in Fig. 6 denotes data bases, or information that must be supplied, by sharp-ended boxes. Rectangles indicate analyses or calculations with models, and round-ended boxes are outputs or intermediate calculated quantities. Geological data should be provided as part of the facility characterization and such data enters directly into the formulation of: logic models for disposal failure, and mathematical models for transport.

The construction of a logic model for a real waste disposal facility requires the provision of detailed, site-specific parameters: waste form and quantity, emplacement geometry, site and regional geology, etc. For preliminary attempts to identify the needed data bases a hypothetical emplacement of nuclear waste deep within bedded rock having an assumed structure is used. This model arbitrarily assumes there are aquifers and permeable strata above and below the emplacement of containers in a deep vault. Construction of the logic model begins with postulating the "top events," such as radionuclides in: ground waters, soil, surface waters, and atmosphere. Next, various events which can, by various combinations, lead up to the top events are arranged using appropriate logic "gates." Basic events generally fall into three categories: 1) events related to geologic processes, 2) events related to human activity in present or future times, and 3) events related to physical action and/or mechanical failures.

Some generic needs from predictive geology which have been identified are:

1. Probabilities that aquifers exist. Size distributions (area and thickness) of aquifers.
2. Probabilities that permeable strata exist (and size distributions).
3. Probabilities that perched, underground pools exist. Volume distribution of underground pools.
4. Probability of faulting. Size distributions (depth and length) of faults.
5. Probability of dissolution fronts. Distributions for dissolution rate and direction.

Figure 6. General flow chart for risk calculation.

Assessment Models for Shallow-Land Burial Site Operations, G. L. Meyer
Environmental Protection Agency, F. J. Davis, Geological Survey -
New York State Science Service. (Other contributors for material
presented were R. H. Fakundiny and J. W. Pferd).

Shallow-land burial sites are existing facilities which can aid in the development of risk assessment methodology for application to deeper disposal of high-level wastes.

The Geological Survey of the New York State Science Service is conducting a multidisciplinary investigation of the fate of radionuclides buried in a low-level radioactive wastes landfill near West Valley in western New York. The study is funded by the U.S. Environmental Protection Agency. The United States Geological Survey is funding a companion study of the site hydrology. The New York State Geological Survey is also participating in this investigation.

The West Valley site has been operated for over ten years. Low-level wastes encapsulated in a variety of containers have been emplaced in trenches which are 500 feet long, 40 feet wide, and approximately 25 feet deep. The excavations are in a fine-grained, moderately impermeable till which exists through the region of the burial site. This same till, taken from the trench excavations, is placed over the waste and compacted to form the cover for the trenches.

The area around the West Valley burial site has experienced significant post-glacial erosion during the last 15,000 years. At present V-shaped valleys have encised what was once a relatively flat region. Relief is now generally at least 75 feet.

Operational conditions at the site have included sufficient rise in ground water levels localized within the completed trenches so that pump down to just below the elevation of the original trench rims has been required on two occasions. Preliminary hydrologic work indicates slow vertical percolation of meteoric water. Lateral circulation is apparently taking place within an extensive, relatively permeable, comparatively coarse unit which is approximately 120 feet below the land surface in the vicinity of the burial site. Trench water buildup appears to be influenced by water infiltration through tensional cracks created in the cap of the completed trenches by differential compaction of the low-level waste material.

This investigation is directed toward development of a comprehensive understanding of the pathways by which radionuclides may be exiting from the waste burial trenches through aqueous, atmospheric, and biologic environments. Systematic sampling is under way to delineate patterns of movement and effects of mineralogy and fracture patterns in the unconsolidated material. It is planned to explore the feasibility of adapting existing computer modeling programs to develop a predictive capability directed toward evaluating future migration and establishing management procedures. These results will also be useful in new site selection in similar terrains.

Introduction to Geosphere Transport of Disposed Radioactive Waste; the Associated Assessment Modeling Problems, C. R. Cole, R. J. Serne, Battelle Pacific Northwest Laboratories.

Models can be divided into two types: physical and mathematical. The latter, in turn, are analytical, finite difference or finite element. A number of other model terms in the jargon are applied. Models may be descriptive or deterministic, black box or transfer function type, one- two- or three-dimensional, and steady state or transient. Other factors for models are a need to calibrate and verify.

The outputs required from a geosphere model include the arrival times, quantities, and concentrations for contaminants at locations where they enter the biosphere.

The basic transport equation may be expressed in word form:

$$\left. \begin{array}{l} \text{Rate of change} \\ \text{of a species in} \\ \text{a control volume} \end{array} \right\} = \begin{array}{l} \text{net advective} \\ \text{flux} \end{array} + \begin{array}{l} \text{net diffusion} \\ \text{flux} \end{array} + \begin{array}{l} \text{net rate} \\ \text{of} \\ \text{production} \end{array}$$

where advective flux is from water flow into and out of the volume.

There are a number of considerations which determine the model design. These include a definition of model use, economic factors of cost for model development and data acquisition, calendar time available, spacial or time resolution required, and the range of parameter variations to be considered.

Modeling of nuclide movement in ground water considers the chemical reactions as the solute moves through a soil column. Reactions are examined on a macro and a micro basis. Experimental results have shown good agreement with model predictions of effluent concentrations.

Migration at the Hanford Site, R. A. Deju, Atlantic Richfield Hanford Company, C. R. Cole, R. J. Serne.

The program at Hanford studying the migration of high level waste was described. Characterization of the Hanford site geology and hydrology was presented along with descriptions of the field studies which have acquired the information.

The present status of predictive modeling is that a model was developed, sensitivity tests have been conducted and the model is operational. Objectives include: 1) evaluation of hydrologic impact of present and proposed water use and disposal facilities, 2) examination of effect of altering ground water flow to reduce spread of subsurface contaminants and or travel times to biosphere uptake points, 3) development of contingency plans, and 4) development of man-machine decision making tools.

Data for indicator wells shows good agreement between predicted and measured migration. Soil profiles for simulated tank leakage show that geologic media acts as a buffer zone. Models are utilized to run scenarios to study catastrophic accident and control problems.

Migration from Burial Grounds, M. L. Wheeler, Los Alamos Scientific Laboratory.

A review of the several shallow land burial grounds in the United States and observations of migration from these facilities was given. One difficulty noted is that where a dry location has been picked for a burial ground, measurement techniques used for wet ground are difficult to apply in a study of burial ground performance.

In the past there have been inadequate specifications for types of waste buried, and no agreement on the degree of containment goal. A definition of "containment" for burial grounds is needed to avoid trouble at a later date. The monitoring systems used need to be accurate.

Cross sections of the stratigraphy were shown for sites at Savannah Rv., Idaho Falls, Hanford, and Los Alamos. Observed releases from some commercial sites were described. Some sites have been shut down because of indications that poor design or poor management have resulted in release of radioactive material.

Migration in the Lithosphere, A. M. Friedman, Argonne National Laboratory.

A simple ion exchange or absorption model has been used to describe

the major features of the migration process of the actinide elements in porous rocks. Discrepancies have been observed between the simple model predictions and empirical observations in the laboratory.

Experiments were conducted with Pu-237 and Am-241 tracers and blocks of tuff. The first type of test was to deposit a sample of tracer on the top of a block, let it dry, and then sprinkle increments of "rainfall" on the block with drying periods between increments. A second type of test studied the effects of various total amounts of "rainfall." The third type of test applied tracer solutions at various deposition rates. Results showed that while the simple model correctly predicted the distances migrated by the peak concentrations, the simple model did not predict a more rapid component that was observed. It is concluded that the rapid movement is an initial surge associated with a transport process called unsaturated flow. Upon addition of solution to the tuff the solution penetrates the pores and fills them for some distance and then continues through the pores as an ever decreasing film in a form of capillary flow. With the rapid film movement, the solute ions do not have time to reach equilibrium with the surfaces and ions thereby appear at greater distances than expected for slow saturated flow.

The effects of unsaturated flow must be considered in modeling any geological storage site. It is important to design a repository to minimize the original surge of a release. This may be done by using a leach resistant waste form and by placing the wastes in a rapidly equilibrating absorption medium. Once the maximum movement of the original unsaturated flow is reached, equilibrium appears to take place and migration becomes much less rapid.

Migration at the Nevada Test Site, L. D. Ramspott, Lawrence Laboratory at Livermore.

The Nevada Test Site is of interest in studies of waste isolation because nuclear weapons testing has directly emplaced "high-level" vitrified waste directly in the groundwater system. Observation of migration from the emplacement sites serves to validate models used for assessment of proposed waste repositories.

The NTS is located within the basin and range physiographic province in an arid region. The west and northwest part is volcanic highland. The

regional and local geology is well-known from complete geologic map coverage and extensive drilling and geophysical logs. An accepted regional hydrologic framework has been established, providing water table levels, hydraulic heads, and groundwater chemistry. However, some aspects of the local hydrology are not well known. The water table lies 1600 to 2300 feet below the surface in the test areas. Of 288 nuclear tests at NTS, 78 have been below the water table. The chimney formed by an explosion ends up with a puddle of rock melt at the bottom containing most of the refractory radionuclides, and volatile components appear in the lower portion of the chimney. Ground water has access to this vitrified waste deposit.

Monitoring at NTS has indicated a substantial degree of radionuclide containment. The only radionuclide observed in groundwater outside of the immediate chimney region is tritium. This observation is based upon monitoring of all drill holes and water supply wells at NTS. Tritium has been observed at only two locations outside of nuclear chimneys. Aside from tritium (2000 times MPC) and Sr-90 (10 times MPC), the water pumped from the Cambrian cavity 10 years after the test would be drinkable. 8×10^8 gallons of water pumped from a well 300 feet away showed no tritium breakthrough.

Sorptive clay and zeolite are found in most NTS alluvium. Eighty to ninety percent of the tuff below the water table in Yucca flat is zeolitized. The high K_d values retard radionuclide migration. Information is available for a one-dimensional model for prediction of radionuclide transport in NTS groundwater.

Geochemical Aspects of Oklo, E. A. Bryant, Los Alamos Scientific Laboratory.

Proposals for storage of radioactive wastes in geologic formations raise questions about long term migration of nuclides from the repository site. It is difficult to conduct experiments that provide valid data for long term predictions, but nature has done so in various cases. It is important to identify these experiments. Oklo is one. In the Gabon Republic, a natural fission reactor went critical 1.8 billion years ago, and remained critical for about 600,000 years. The ore body in the Oklo mine occurs in a sandstone layer at an average slope of about 45°, and is several meters thick. Several reactor zones have been identified in a vein of rich ore

about one meter thick within the ore body.

Comparison of the isotopic ratios of stable isotopes of the element neodymium in samples from the Oklo mine with other natural occurrences and with fission-produced neodymium is one of the confirmation techniques used.

Concentrations of fission products (or their ultimate stable daughters) in the reactor zone and in the surrounding formation have been studied to determine migration. At least half of the approximately 30 fission-product elements have remained immobilized in the ore. These include the rare earth elements and chemically similar yttrium. Most or all of zirconium, ruthenium, rhodium, palladium, niobium, and silver remains; along with some molybdenum and iodine. Traces of the inert gases krypton and xenon remain. Metals with a valence of one or two readily leach into water. Therefore, rubidium, cesium, strontium, barium, and cadmium have mostly disappeared. Plutonium and neptunium were retained. Retention of these actinides is important for waste disposal implications.

There is a very good possibility that other natural reactors have existed in the past.

Interpretative Summary of Oklo, D. G. Brookins, The University of New Mexico. (Comments offered at the beginning of the last workshop session.)

Plutonium was retained in uranium crystals at Oklo because of favorable oxidation potential (Eh-pH) conditions resulting in retention of Pu in almost ideal solid solution with U at pH above 2. On the other hand, some uranium did migrate at Oklo. This and observed migration of molybdenum can be explained by considering oxidation states and the related geochemical environment.

In a waste repository, we can take advantage of the chemistry of Am, in that it behaves almost identically to europium. Europic oxides can be produced commercially and introduced to the waste system to cause americium to become locked up in solid solution. Ca and/or Ba salts can help tie up any Sr that is present.

What one sees at Oklo is a shale and not a very good one at that. Retention of radionuclides and their stable daughter products in the

formation is significant. This gives hope that criteria can be developed for a more proper assessment of better quality shales as a repository.

Evidence indicates that migration of barium did not begin until after some 25 million years. The alkaline earth elements were not completely removed over 1.8 billion years.

There is considerable potential for applying geochemical processes to provide for lock-up of the waste species in a repository. Proper selection of disposal formations and introduction of additional materials can take advantage of the natural processes. The problem to be addressed is to integrate data and work it into a viable model.

SESSION 4 DISCUSSION PERIOD

The formal agenda of background technical presentations was completed during the early portion of Session 4. The balance of this session was devoted to informal discussion led by H. C. Burkholder, S. E. Logan, and P. E. McGrath, representing the ERDA, EPA, and NRC assessment model teams, respectively. The discussion quickly developed into a lively exchange of views, with proponents on both sides of almost every point brought up. As a rigid format was not followed, the trends of discussion probed out in one direction, sometimes with a debate along the way, was then brought back to probe in another direction, and so on. In following paragraphs, the broad range of ideas expressed are collected into appropriate subject groups; instead of in the actual sequence.

Purposes and Objectives of Models

Results obtained from models are used as a part of the decision making process. Different agencies have different requirements; each needs to determine model use and associated model output, and the corresponding model characteristics in order to define needed input. It was suggested that the following uses provide for meeting the goals of the various agencies:

1. Setting criteria
2. Evaluation of waste management alternatives
3. Repository site selection
4. Feedback to repository design
5. Site assessment for licensing
6. Add to understanding of the technology
7. Communication to the public.

In order to place the subject into perspective, an administrator from the NRC (W. Bishop) presented views as a user of model output, addressing the question: "Why do we want a model?" NRC uses are primarily for:

- 1) Development of criteria necessary for a repository: i.e., the performance it must meet.
- 2) Licensing of repository: assurance of safety in the long term.

As described during the formal agenda of the workshop, uses by the EPA are:

- 1) Compare and assess proposed storage/disposal concepts.
- 2) Develop generic ability to evaluate environmental acceptability of fuel cycle facilities.
- 3) Develop technical bases and guidelines for establishing environmental policy relative to commercial wastes.
- 4) Assist in developing criteria and standards relating to waste management.

ERDA applications for assessment models include:

- 1) Compare proposed storage/disposal concepts for program planning and funding purposes
- 2) Evaluate designs of waste management facilities and indicate needed design revisions.

Two questions generally asked concerning a proposed waste repository are: 1) is it safe?, and 2) how do you know it is safe? There is a difference of opinion as to where a model should enter the picture. Should a model be limited to evaluation of consequences of various events if they occur, with dependence upon the judgment and experience of geologists to make a qualitative determination of whether such events can occur? Or, should a model also include the probabilities for occurrence of the various potential release events? Actually, a flexible model may be operated in either of these two modes. The judgment and experience of geologists can be quantified into appropriate probabilities, though some consider "predictive geology" to be beyond present capabilities. Either way, modeling aids in a decision by balancing consequences against events. An importance of models is in laying out the reasoning of why failure mechanisms will or will not occur. It is not adequate to say a system is safe; others must be convinced to agree.

Some of the discussion of model purposes revolved around the question of generic or general models versus site-specific models. Usually, a generic model is constructed first. This provides a basic model structure and defines the questions which should be asked. The site-specific model determines the answers being sought. This can be by simply entering appropriate numerical values in the generic model, or it may first involve modifications in the generic model to provide representation of specific

site characteristics.

Given enough time, slow geologic processes will breach containment; however, if this time is long enough, radiodecay cancels the further need for containment. Models help in determining consequences to define the containment time needed.

Types of Input Data Needed

Consideration of types of data needed for input to models is limited here to geologic data related to: 1) events which can result in release of radionuclides to the geosphere, and 2) geosphere transport parameters. Other categories of model input such as transport through environmental pathways were not included within the scope of the workshop.

Geologic data needs thus fall into two general categories: 1) probabilities for occurrence of events which may initiate release, and 2) geosphere transport parameters for evaluation of the consequences of a release. The latter was frequently referred to as the "what if" consequence. It was observed that if evaluation shows that a particular "what if" has negligible consequences, the need for probabilistic data for that event is negated.

Geologic events may be subdivided into rate processes and catastrophic events. The first of these, also called degradation, are slow geologic changes. These occur at all sites and can be predicted within limits. Catastrophic events require estimates of probabilities. A formation dimension large enough to preserve containment, considering the maximum rates of geologic rate processes, and a formation which provides containment even if catastrophic events take place, would be ideal.

There was disagreement over the feasibility of listing data requirements in a generic sense versus first requiring identification of a specific site. Some persons believed a proposed site must be selected and characterized before specific model data requirements can be determined. Others, including persons working on models for several years held to the view that a general "shopping list" can be determined first and then tailored to a specific site with deletions and additions as appropriate. It is suggested that properly used, models can help greatly in the initial site screening and selection process.

An iterative process was suggested. It is difficult to fully define the quantity and accuracy of needed data at the outset. The iterative process uses limited data readily available for a "first cut," substitutes better data as it becomes available, progressively determines needed accuracy, and isolates the more important data items for additional field study.

The topic of site criteria produced a diversity of views. Some stated we presently have no criteria and that there is nothing to be gained in attempting to implement assessment models until criteria are set up. On the other hand, it was stated that one important use of the models is to assist in determination of site criteria. The OWI view is that sites will be selected which provide complete containment for thousands of years and the models help evaluate the consequences if something goes wrong. It was also observed that criteria established by experts in the field are subject to final decisions determined by the public through their representatives in Congress and through the Courts.

The discussion during this session of the workshop dwelled on generalities of model applications, whether geologic predictions are feasible, whether adequate funds are available for data collection, generic versus site specific questions, and the question of criteria. A preliminary list of geologic properties and events was distributed for discussion purposes. This list grouped several dozen items under the following headings: 1) Structure of Area, 2) Tectonics, 3) Volcanic and Plutonic Action, 4) Hydrology, 5) Geochemistry, 6) Faulting, 7) Rock Mechanics, and 8) Erosion/Deposition. The diversity of views on the generalized questions was such that the dialogue precluded progress on the list of needed data.

Doubts About Use of Models

A variety of doubts and reservations were expressed about the use of models. There are only 30 years of experience to date with tracing nuclide movement in groundwater. The accuracy of ground water transport predictions for one-half million years is therefore questioned. This depends upon what accuracy is actually needed, but in any case models are useful to be sure that all factors are considered.

It was suggested that all of the problems concerning selection and assessment of a repository site do not necessarily rest on the lack of data; perhaps we need some conceptual development or theory in order to properly use any new data collected.

A question was raised as to the capability to predict ecosphere factors a long time into the future. It is noted that models can be applied for a range of possible climate conditions to bracket future changes without necessarily needing a time dependent prediction.

One category of concern frequently brought up appears to be associated with misconceptions about the assessment models currently being developed. Concern was expressed that there is an attempt to automate the decision making process and that once various inputs from various disciplines enter a model, further interaction with individuals in those disciplines is cut off. Computerized models are viewed by some as an attempt to "remove experience." Also, it appeared there was an incorrect impression that models have been put together without participation by specialists such as geologists.

It was repeatedly pointed out that while geologists know what happened before, they are very reluctant to predict the future. It was stated that it is impossible to quantify such things; one must plug in the experience of qualified geologists even if it takes 100 in a room coming to a consensus. A thought was expressed that perhaps we should take votes among 500 geologists if need be to determine numerical values to be used in a model. The general response of "modelers" was that if this is what it takes, let's do it. It must be noted here, that society demands that predictions of the future be made, by one means or another.

One misconception is that models attempt to simulate details of complex geologic processes: "Modelers want an equation to plug into the model to get joint spacing and width." Provisions such as this need be included within a model only to the extent feasible. Analytic treatment of ground water flow is quite well developed, for example. Other geologic changes can be evaluated externally to the assessment model, using other geologic models, panels of experts, or by votes among a multitude.

An interesting concept was raised concerning the role of the modelers. Much of the discussion related to obtaining the data for assessment input.

An inverse model application was suggested: perhaps the modeler should provide guidelines for a needed parameter (such as permeability) for nuclide retention. This would be input to the geologist as a required condition to look for and represents the "determination of criteria" model application discussed previously.

A reservation that came up a number of times related to: 1) whether a model can be constructed before a specific site is selected or not, 2) whether one must start from scratch for each such model, and 3) whether funds would be available for such efforts. This is the generic versus site-specific model question. A flexible generic model need only involve adaptation to a specific site.

The cost of collection of data required for model implementation was a source of concern and is discussed in following paragraphs.

Expense of Data Collection

Whenever the discussion began to move toward naming types of data needed, the question was raised as to whether enough money was available to get the data. This was, of course, beyond the intended scope of the workshop, since costs cannot be addressed prior to: 1) listing needed items of data, and 2) defining extent and accuracy required. Some were reluctant to consider an item of data unless the modeler would simultaneously state required accuracy. It was stated that geologists must know the purpose of a model to know the kind of detail to impose. It was noted that the required effort to get a data item could range from a day on up to a huge geochemical program. For example, detailed K_d (distribution coefficient) data can involve up to tens of millions of dollars for one site. On the other hand, published data may exist which is adequate for model purposes in some cases, or a few field samples may suffice.

A fear was voiced that modelers might be requesting detailed data for each and every potential site being considered and this would be prohibitively expensive. For this reason, some believe the modeler should enter the picture only at a later phase after other considerations have led to interest in a specific site. This, of course, overlooks the possibility of obtaining all needed model data in the course of other site selection work, without necessarily involving additional expense. It also overlooks the important possible contributions by models to identify

possible cause for rejection early in the selection effort thereby conserving funds. Again, the iterative approach appears to be appropriate: apply a model with initially available data and update as the site selection process proceeds.

The Complete Containment Concept

The intention of the OWI is to qualify a site on the basis of having a formation which provides complete containment for 250,000 years. Once such a criterion is established, it implies there is need only for general site properties associated with mitigation of consequences should a disruption of the repository occur. Most of the concern by the OWI is on determining a freedom from initiating events as derived from site characterization data obtained during the site investigations, instead of concern for data associated with transport. Thus, planned data includes general hydrologic parameters, identification of aquifers above and below the disposal horizon and near-surface hydrologic details. Data acquisition not planned includes sorption characteristics such as K_d values. OWI has less interest now in systems where ion exchange and slow water movement are relied upon to contain waste. Of course, some general data on water movement, sorption, etc., are viewed as needed to assess waste migration in case of release through occurrence of improbable catastrophic events.

The philosophy of complete containment without inclusion of additional environmental barriers was vigorously challenged by many in attendance. It was argued that there are three barriers available: 1) containment by the formation, 2) leach resistance in the event that containment is breached, and 3) nuclide retention by sorption in surroundings. All of these may be needed for defense of a selection in public forums. A view shared by a number of persons is that qualification should be based upon the sum of all of the containment barriers. However, it was noted that whether one or all barriers are considered, it is probably impossible to find a site that can provide containment for any and all scenarios that might be "dreamed up." The question was raised: If a site is picked for complete isolation, i.e., containment without failure, how does one know without use of a model that one has complete isolation and containment without failure? This question encounters the previously mentioned difference of opinion as to where a model should enter the picture.

On one hand it is argued that a model does not prove containment, that only geologic data can do it; there is nothing to model unless there is failure. On the other hand it is argued that some models include an evaluation of combinations of events which can lead to failure; the model provides a logical format for combining the geologic data to establish the probability of containment.

Selection of a site before evaluation of the consequences of containment failure was questioned; this should be part of the selection process. While a general assessment is made through seismic studies, hydrologic conditions, etc., part of the criteria for determination of whether a site is acceptable may be such items as the K_d values. The proponents of the complete containment philosophy argued that a site selection can be made with reasonable confidence prior to making a big data acquisition effort and that evaluation of failure mechanisms should be largely a follow-on activity once the complete containment criterion is satisfied and the site has been accepted for detailed evaluation. This suggests a belief that evaluation of failure mechanisms must involve a big data effort but this is not necessarily true if an iterative approach is taken to model implementations.

One suggestion was that either an independent team of geologists and modelers should obtain the data needed for models or that one should start with a simple model using "standard data," work with it until the site is "qualified" and add detailed data later when the most probable failure event is identified. This partly suggests the iterative approach mentioned earlier, but it does not provide for obtaining an extension of "standard data" for evaluation of consequence mitigation. This carries some risk of a late rejection of a site after it is "qualified," instead of considering all applicable factors in the qualification process.

Additional Points Discussed

There are several important systems which provide real data for checking migration predictions by models. These include: 1) the Nevada Test Site deposits from weapons testing, 2) the Oklo ancient natural reactor, and 3) the Hanford reservation liquid waste storage.

It was suggested that there are three approaches for providing waste repository safety which have a parallel in methods used for reactor safety:

1. Quality assurance.

This is based upon good engineering, a good site (criteria for this are needed), and doing the best job possible.

2. Risk approach.

This assesses the risk associated with a system and is very difficult. It is particularly good for trade off studies, and comparison of a site risk with other risks which people do or do not accept.

3. Combination of 1 and 2.

Current opinion is to concentrate on the quality assurance approach assisted by models. One view was that probabilistic analysis is premature unless used on a comparison basis.

At some point in the repository site and emplacement method selection and the safety assessment, whether willing or not, we will quantify in order to make decisions.

SESSION 5 (FINAL) DISCUSSION PERIOD

The final session of the workshop was led by W. Twenhofel of the USGS. After a short additional presentation on Oklo (D. Brookins), described earlier with the formal agenda summary, discussion proceeded with the objective of summing up the meeting in a positive way. During Session 4 the previous afternoon, opposing viewpoints were freely expressed. In the interim, informal discussions began to resolve differences of opinion and to clarify misconceptions. The final session worked out a list of items to be jointly attacked by geologists and modelers. In a broader sense, the items are for attack together by all types of earth scientists, chemists and physicists. That is, scientists including modelers must work together on some problems that we as a technical community face and also we as a society face.

The list of problems needing attention which was obtained is presented in Table 1. As it stands, this list is not a list of data items needed as model input. Instead, it is a step toward determining model input. Most of the items in Table 1 are events or factors which may relate to release events. There is a dependence of items on the time frame: operational versus long-term periods. The low probabilities for catastrophic events and the slow rates for the chronic events relegate these items generally to the long-term phase. Man-made events may be divided between the repository operations phase, the long-term phase, or applied to both.

It was pointed out that there are two categories of changes: 1) natural geologic processes which are independent of introduction of a repository, and 2) perturbations induced by the presence of the repository. In this connection, if the system is designed for minimum perturbation, the first category of changes becomes dominant. In such a case, past history may provide adequate prediction of future behavior. It was further observed that many of the man-made events can be avoided or accommodated by proper engineering design. Also, consequences of events which occur during the operations phase can be mitigated to various extents by repair or clean-up work.

There was some attempt to assign priorities to items in Table 1, but it became apparent that this depends upon consideration of specific sites and there was insufficient time to consider some representative candidate

Table 1. Problems needing attention jointly
by geologists and modelers.

I. Catastrophic events

A. Random events

1. Meteorite impact
2. Hurricanes

B. Non-random events

1. Earthquakes/seiche/tsunami (ground and water motion)
2. Landslides
3. Volcanic
4. Faulting (intrusion of repository or nearby area)

II. Chronic geologic events

A. Dissolution

B. Rheology - time dependent (rock behavior)

C. Time-dependent permeability

D. Thermal changes

E. Surficial processes

1. Glacial/pluvial/sea level variation
2. Erosion/sedimentation
3. Landslides
4. Subsidence/uplift

F. Chemical Effects

III. Man-made events

A. Repository operations phase

1. Mine flooding
2. Fires/explosions

B. Long-term phase

1. Intrusion-overt or inadvertent (drilling, mining, hydrofracture)
2. Hydrologic stresses (irrigation, dams)
3. Subsidence following mining
4. Activities enhancing transport of released radionuclides

C. Repository operations and long-term phases

1. Interaction of waste with host rock
 - a. Thermal loading
 - b. Radiation effects
 - c. Chemical
 - d. Mechanical (structural failure of hole and shaft sealings)
2. Warfare
3. Other ("residual risk")

sites. There was general agreement that faulting is a top priority item along with the correlated question of whether a fracture heals by plastic flow or stays open.

A suggestion was made that assessment modeling be split up into three successive steps with a separate model for each:

1. Operations period. This is the approximately 50-year period during which man-made impacts such as mine flooding or spills are dominant.
2. Storage for first 1000 years. This is the period during which a hazard from short-lived to intermediate-lived components of waste, such as Sr-90 and Cs-137, exists. A 1000-year period of time is a short time for geological prediction.
3. Long-term period. A model for the period beyond 1000 years can consider migration pathways in the geosphere and include probabilities of release events.

It was suggested that presentation of results from three such models applied to a specific site would provide a more easily understood sequence to convince people in the vicinity of the site and the regulatory authority that a proposal is acceptable. The EPA model developed at UNM applies this philosophy, at least in part. The total time at risk in the EPA model is divided into four phases: storage at the reprocessing plant, transportation to the repository, repository operations, and terminal (long-term) storage. Risk is calculated separately for each phase with consequences evaluated over all subsequent time in each case. The terminal storage phase may be further divided into two or more periods if desired.

A follow-on suggestion related to the above is that a matrix of data requirements be set up. Such a matrix would list event probabilities and other parameters, needed for assessment model input, opposite each of the time frames: 1) site characterization (i.e., the present time), 2) 50-year period, 3) 10^3 year period, and 4) 10^6 year period. A caution was introduced that the sequence in which the impacts are encountered does not necessarily represent the ordering of importance of the needed data.

The importance of characterizing the site was emphasized. Many of the parameters are not changed by addition of the repository.

An interesting observation was made relating to the Oklo site. While this natural reactor was certainly not cited in accordance with any repository criteria, a study of the Oklo site indicates that even a questionable choice for that "repository" resulted in rather good containment against migration. Another observation is that migration associated with components of radioactive waste can be expected to exhibit parallalism with various chemically similar minerals. This can help in making some of the needed predictions.

The workshop concluded with a review of results versus planned objectives, included in the following conclusions section. Suggestions were made that: 1) a matrix categorizing data items be prepared, 2) that the matrix be submitted to geologists and modelers, and 3) a later follow-up meeting be held.

CONCLUSIONS

It has been stated before the workshop, during the workshop, and also in this report, that two general categories of persons attended: 1) earth scientists, including persons actively studying potential waste repository sites, and 2) model builders, who are developing technology assessment models for application to various waste management phases. While this division is convenient, it should be kept in mind that some people wear both hats at one time or another, and that modelers are engineers and/or scientists working at this time to relate and bring together interdisciplinary contributions. This workshop sought to define needed geologic data input for assessment models; release to and transport through the geosphere is the most difficult part of such models. Modelers also interface with other disciplines including biologists, health physicists and economists for other parts of the models.

A clearly defined list of data needs was not obtained, but the nature of the problem was redefined to be primarily a need for communication between the two groups. Some geologists have participated as consultants during model development work but the earth scientist community in general is not familiar with the model work. Along with this, the modeler has not received as broad an input from geology as would be liked. The workshop started a dialogue which helps both groups to understand the other's problems.

There is general agreement that assessment models are useful and are needed by various agencies as a tool in decision making. There are different opinions as to what scope a model should have and the timing for its application. A model should not automate decision making; there should be continued participation by specialists for interpretation of results.

A flexible model, in addition to having a capability to evaluate the consequences of various initiating events, should provide for probabilistic input data for those events. Such a model can be operated in either mode: "what if" only, or including a probability analysis, depending upon the objectives of the model user.

A model should start as a generic model and evolve into site-specific implementations as needed. It is not necessary nor is time available to "start from scratch" for each site. Correspondingly, the input data can

be progressively augmented and refined as a study progresses. It is not possible at this time to rigidly specify the required completeness and accuracy of various needed geologic data. Initial input permits sensitivity analysis to define which data items need improvement and which items have little effect on results.

Models should be introduced early in the site qualification process and not used only as a fingers crossed follow-up confirmation process. Late rejection because of inadequate protection against nuclide migration is not cost effective. Models can help in defining the required containment time and can help in setting criteria for site qualification.

Selection and qualification of a candidate repository site should be based upon the sum of all of the containment barriers: 1) containment by the formation, 2) leach resistance, and 3) nuclide retention by sorption and limited ground water movement.

Geologic data needs fall into two general categories: 1) probabilities for occurrence of events which may initiate release, and 2) geosphere transport parameters for evaluation of the consequences of a release.

A list of items, Table 1, to be jointly attacked by geologists and modelers was worked out. Most of the items are events or factors which may relate to release events. An associated list naming data items such as probabilities of occurrence, predicted extents and rates, etc. can be developed from the list of events. In addition, data related to nuclide transport is needed for consequence evaluation. It is hoped that this report will serve as a catalyst for maintaining movement toward meeting the geologic data needs for assessment models. A follow-up meeting at a later date may be fruitful in evaluating progress and providing future guidance.

APPENDIX A. List of Attendees

WORKSHOP ON GEOLOGIC DATA REQUIREMENTS
FOR RADIOACTIVE WASTE MANAGEMENT ASSESSMENT MODELS

Santa Fe, New Mexico; June 28-Jul 1, 1976

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